Institute of Chartered Foresters

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School of Computing, Engineering & the Built Environment

# Wood properties & strength grading

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SIRT

Strategic Integrated Research in Timber

# Issues using wood

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- Water
- “Figure” and “Defects”
- Anisotropy (not the same in all directions)
- Inhomogeneity (not the same in all locations)
- **Variation and uncertainty**

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# Some properties that matter

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- Strength (bending, tension, shear, perp to grain, fracture etc…)
- Stiffness
- Density (fasteners, charring rate, self-weight, calorific value…)
- Hardness, toughness, tendency to split
- Dimensional stability / distortion
- Natural durability / difficulty to treat
- Appearance, colour and colour change
- Creep
- Cutting, finishing, gluing, painting etc

# Durability

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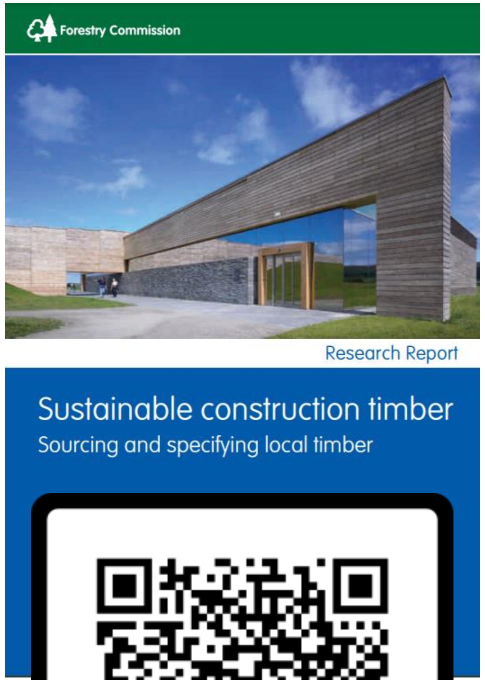
- Natural durability (heartwood only) (EN350)
- Via treatment
- Through design and detailing

- Use classes (EN335)

1. Internal, will not get wet
2. Internal, but might get wet occasionally
3. Outdoors, above the ground
4. Outdoors, in ground contact or fresh water
5. In seawater

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# Structural engineering

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

(There is always some uncertainty)

# Dealing with uncertainty

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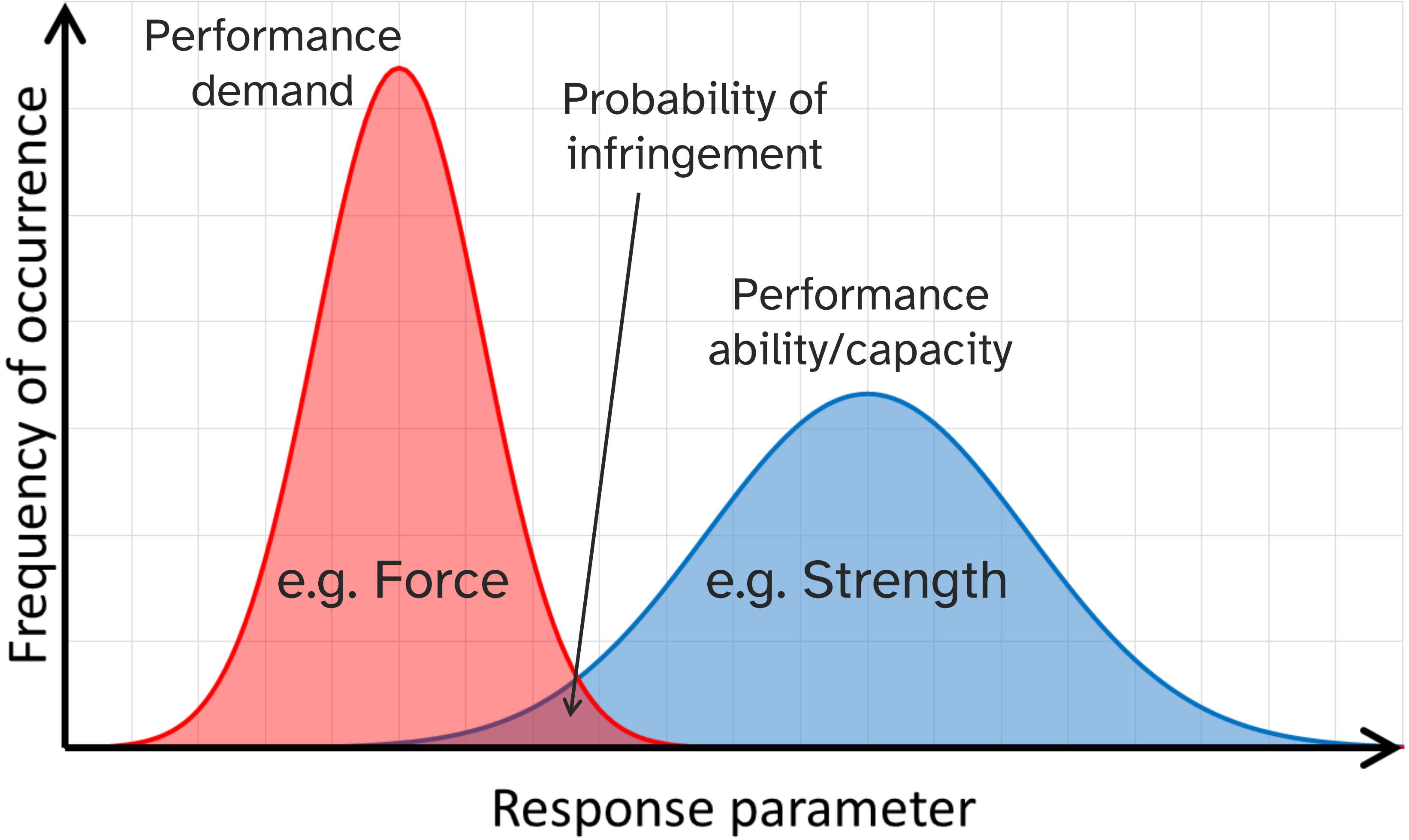

# Statistics (as engineers see them)

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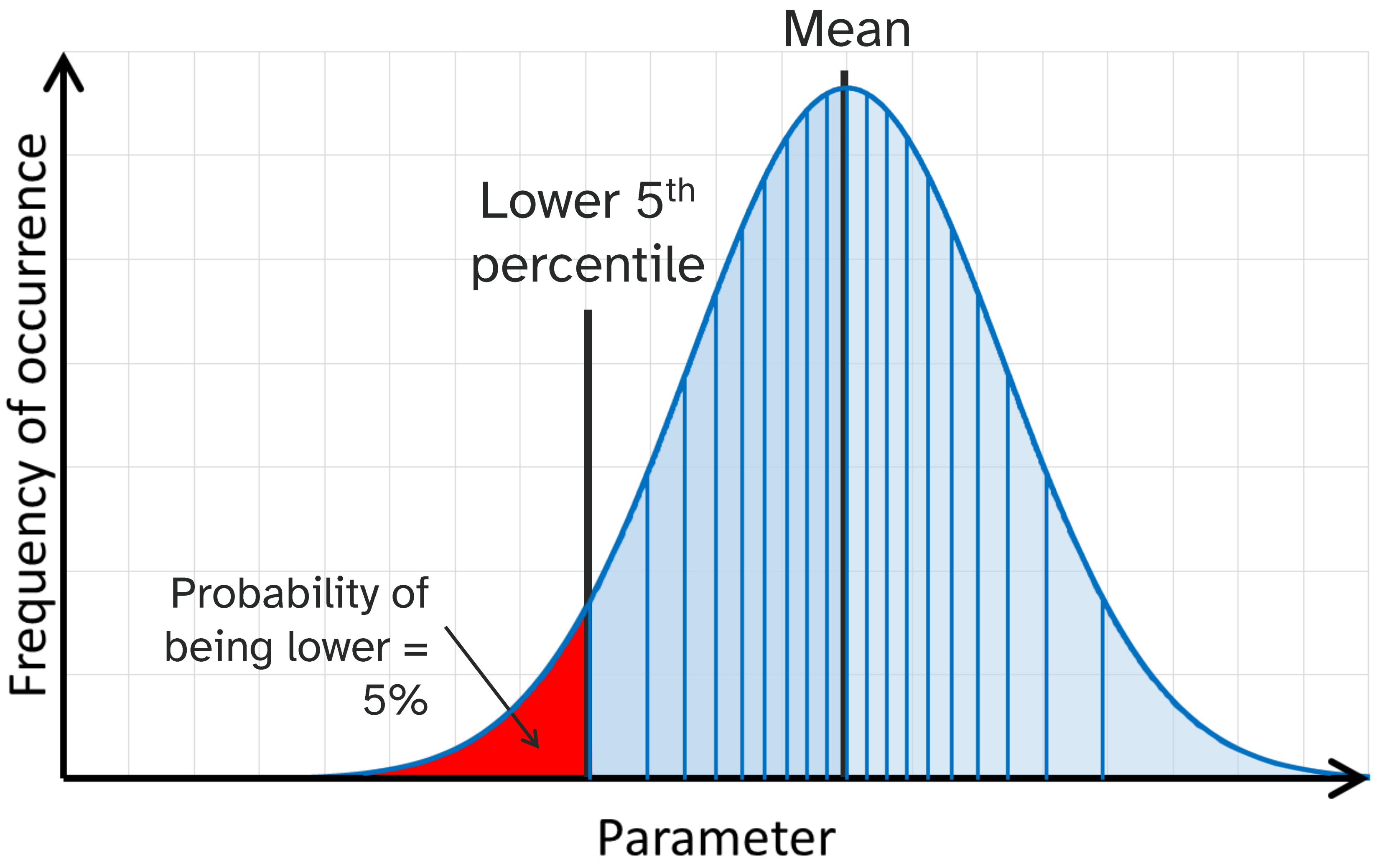

# Grading is about populations

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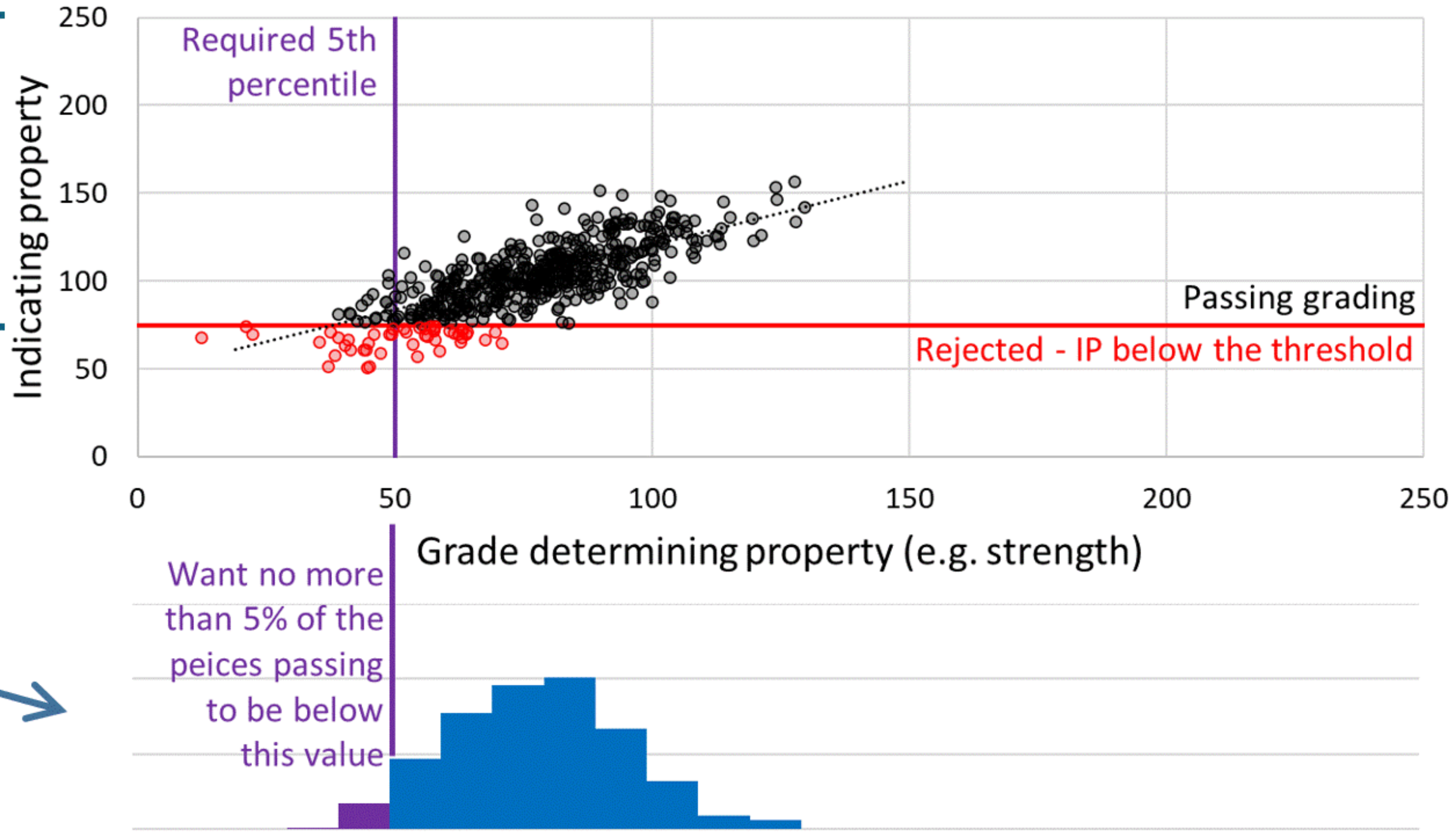
The histogram is for the timber passing the grade



# Grade determining properties

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- **Strength**
  - Bending or tension strength
  - Characteristic is the **5th percentile**
- **Stiffness**
  - Bending or tension stiffness
  - Characteristic is the **mean**
- **Density**
  - Used for indirect measure of strength / fire resistance (this is not density for dead weight)
  - Characteristic is the **5th percentile**


LEE

# EN338

| | Class | C14 | **C16** | **C18** | C20 | C22 | **C24** | C2[illegible] |
|---|---|---|---|---|---|---|---|---|
| **Strength properties in N/mm²** | | | | | | | | |
| Bending | $f_{m,,k}$ | 14 | **16** | **18** | 20 | 22 | **24** | [illegible] |
| Tension parallel | $f_{t,0,k}$ | 7,2 | **8,5** | **10** | 11,5 | 13 | **14,5** | [illegible] |
| Tension perpendicular | $f_{t,90,k}$ | 0,4 | **0,4** | **0,4** | 0,4 | 0,4 | **0,4** | [illegible] |
| Compression parallel | $f_{c,0,k}$ | 16 | **17** | **18** | 19 | 20 | **21** | 22 |
| Compression perpendicular | $f_{c,90,k}$ | 2,0 | **2,2** | **2,2** | 2,3 | 2,4 | **2,5** | 2,5 |
| Shear | $f_{v,k}$ | 3,0 | **3,2** | **3,4** | 3,6 | 3,8 | **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** | 1[illegible] |
| 5 percentile modulus of elasticity parallel bending | $E_{m,0,k}$ | 4,7 | **5,4** | **6,0** | 6,4 | 6,7 | **7,4** | [illegible] |
| Mean modulus of elasticity perpendicular | $E_{m,90,mean}$ | 0,23 | **0,27** | **0,30** | 0,32 | 0,33 | **0,37** | [illegible] |
| Mean shear modulus | $G_{mean}$ | 0,44 | **0,50** | **0,56** | 0,59 | 0,63 | **0,69** | 0,[illegible] |
| **Density in kg/m³** | | | | | | | | |
| 5 percentile density | $\rho_k$ | 290 | **310** | **320** | 330 | 340 | **350** | 360 |
| Mean density | $\rho_{mean}$ | 350 | **370** | **380** | 400 | 410 | **420** | 43[illegible] |

# EN338

| | Class | D18 | **D24** | D27 | **D30** | D35 | **D40** | D45 | **D50** | D55 | **D60** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Strength properties in N/mm²** | | | | | | | | | | | |
| Bending | $f_{m,,k}$ | 18 | **24** | 27 | **30** | 35 | **40** | 45 | **50** | 55 | **60** |
| Tension parallel | $f_{t,0,k}$ | 11 | **14** | 16 | **18** | 21 | **24** | 27 | **30** | 33 | |
| Tension perpendicular | $f_{t,90,k}$ | 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** |
| 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** |
| Shear | $f_{v,k}$ | 3,5 | **3,7** | 3,8 | **3,9** | 4,1 | **4,2** | 4,4 | **4,5** | 4,7 | **4,8** |
| **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,[illegible]** |
| 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[illegible]** |
| 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,[illegible]** |
| 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** |
| **Density in kg/m³** | | | | | | | | | | | |
| 5 percentile density | $\rho_k$ | 475 | **485** | 510 | **530** | 540 | **550** | 580 | **620** | 660 | **700** |
| Mean density | $\rho_{mean}$ | 570 | **580** | 610 | **640** | 650 | **660** | 700 | **740** | 790 | **840** |

# EN338

| | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **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,[illegible] |
| Tension parallel | $f_{t,0,k}$ | 8 | 9 | 10 | **11** | 12 | 13 | **14** | 14,5 | 15 | 16 | **18** | **21** | **22** | 24 | 26 | [illegible] |
| 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 | [illegible] |
| Compression parallel | $f_{c,0,k}$ | 16 | 17 | 17 | **18** | 19 | 20 | **21** | 21 | 21 | 22 | **23** | **25** | **26** | 27 | 28 | 29 |
| 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 |
| 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 |
| **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 |
| 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, |
| 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 | 0,5 |
| 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 |
| **Density in kg/m³** | | | | | | | | | | | | | | | | | |
| 5 percentile density | $\rho_k$ | 290 | 300 | 310 | **320** | 330 | 340 | **350** | 350 | 360 | 370 | **380** | **390** | **390** | 400 | 410 | 410 |
| Mean density | $\rho_{mean}$ | 350 | 360 | 370 | **380** | 400 | 410 | **420** | 420 | 430 | 440 | **460** | **470** | **470** | 480 | 490 | 490 |

# UK softwood summary

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| | Species | Research* | Data | Ungraded | | | From 95% machine yield | Fungi, EN350 |
|---|---|---|---|---|---|---|---|---|
| | | | | Strength | Stiffness | Density | Grading | Durability |
| Grading options | Spruce (UK & IE) (Sitka & Norway) | ENU, FR, NUIG | 😎 | C16 | C16 | C20 | C16 to C27 | 5-4 |
| | Larch (UK & IE) (European, Japanese, hybrid) | ENU, FR, NUIG | 😆 | C20 | C20 | C40 | C20 to C35 | 4-3 🙂 |
| | Douglas-fir (UK & IE) | ENU, FR, NUIG | 😆 | C14 | C22 | C35 | C16 to C40 | 4-3 🙂 |
| | Pine (UK & IE) (Scots & Corsican) | ENU, FR, NUIG | 🙂 | C20 | C18 | C40 | *C16 to C24* | 4-3 🙂 |
| No grading options | Noble fir | ENU, FR | 🙂 | C14 | C16 | C18 | C16? to ? | 4 |
| | Western red cedar | ENU, FR | 🙂 | C16 | C14 | C16 | C16? to ? | 3 😆 |
| | Western hemlock | ENU, FR | 🙂 | C18 | C16 | C30 | C16? to ? | 4 |
| | Silver fir | ENU, FR | 🤪 | C20 | C16 | C27 | C16? to ? | 4 |
| | Grand fir | ENU, FR | 🤪 | C16 | C14 | C18 | C16? to ? | 4 |
| | Pacific silver fir | ENU, FR | 🤪 | C18 | C18 | C16 | C16? to ? | ? |
| | Serbian spruce | ENU, FR | 🤪 | C16 | C18 | C40 | C16? to ? | ? |
| | Japanese red cedar | ENU, FR | 🤪 | C14 | <C14 | <C14 | C14? to ? | 5 |
| | Nordmann fir | ENU, FR | 😔 | <C14 | C18 | C30 | C14? to ? | ? |

**blogs.napier.ac.uk/cwst/**

Durability is for heartwood against fungi. 5 = 'not durable'; 4 = 'slightly durable', 3 = 'moderately durable'
Pine grading options are limited and probably not optimal
* ENU = Edinburgh Napier University; FR = Forest Research; NUIG = National University of Ireland, Galway

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# Properties are influenced by

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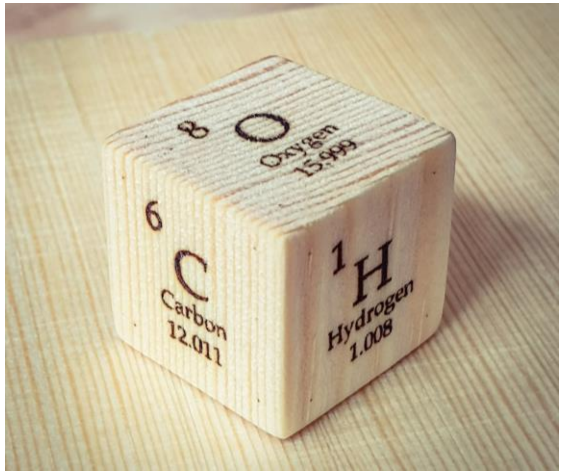


- **Species**
- **Growth area**
- Forest type, & management
- Tree selection & breeding
- Processing
- Handing after processing

# “Quality” indicators

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- Species?
- Origin?
- Knots?
- Slope of grain?
- Ring width?
- Density?
- …

# “Quality” indicators

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1. Things that determine quality directly
2. Things that correlate with quality somehow

# A key thing about indicators

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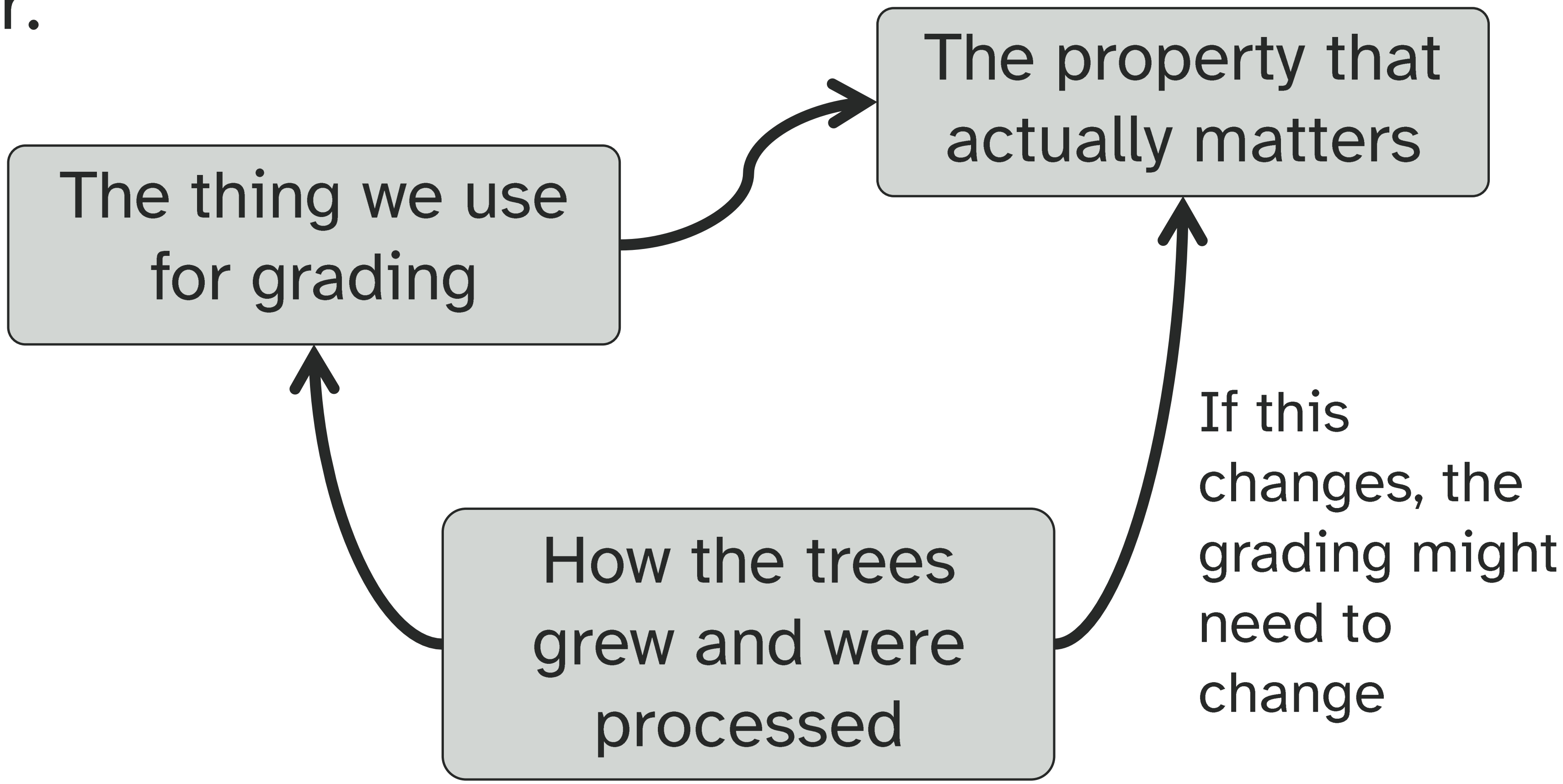
They can be useful for grading, but are often not deterministic

Especially for:

Knots

Ring width

Density



# Density & bending strength

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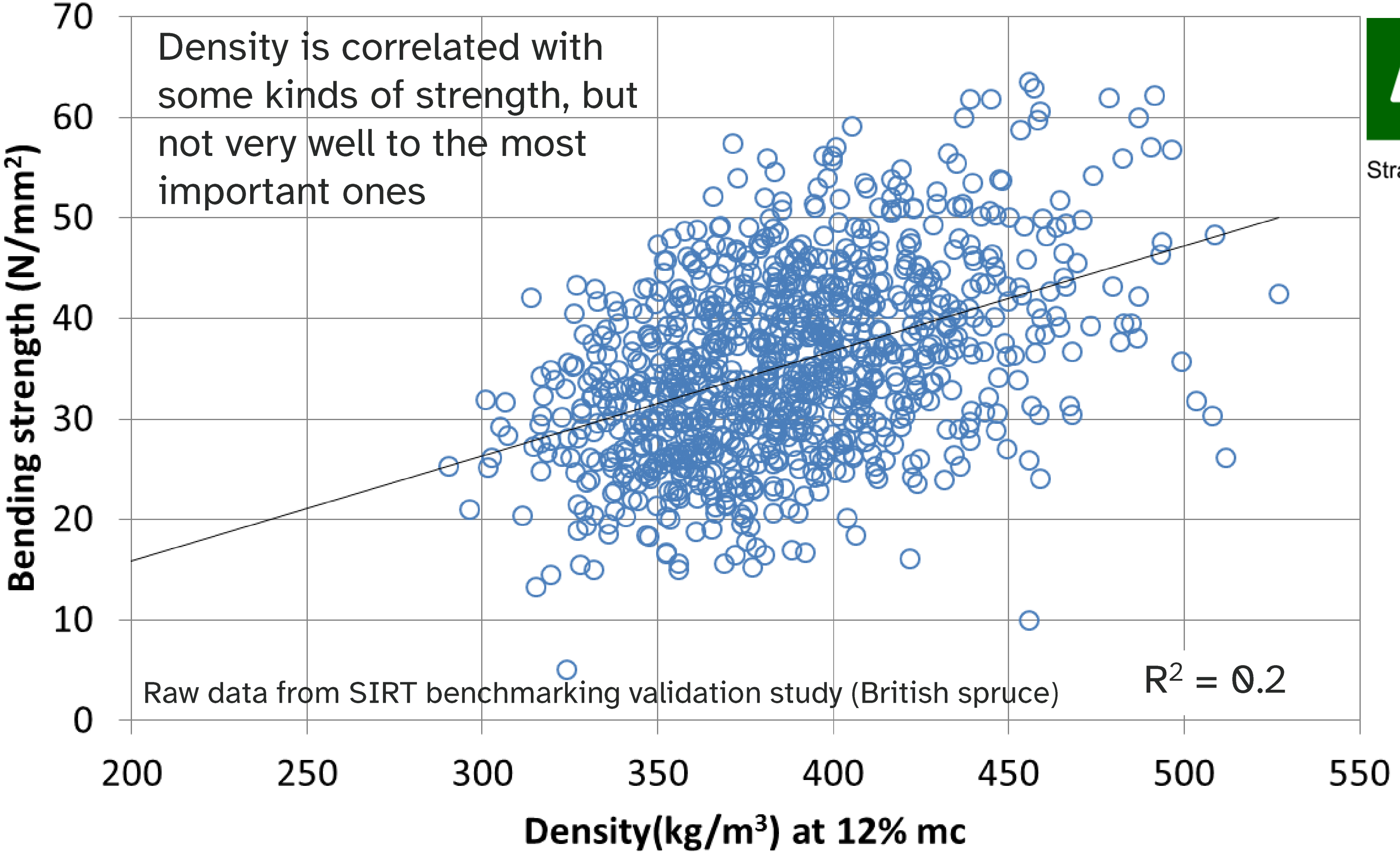


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# Stiffness & bending strength

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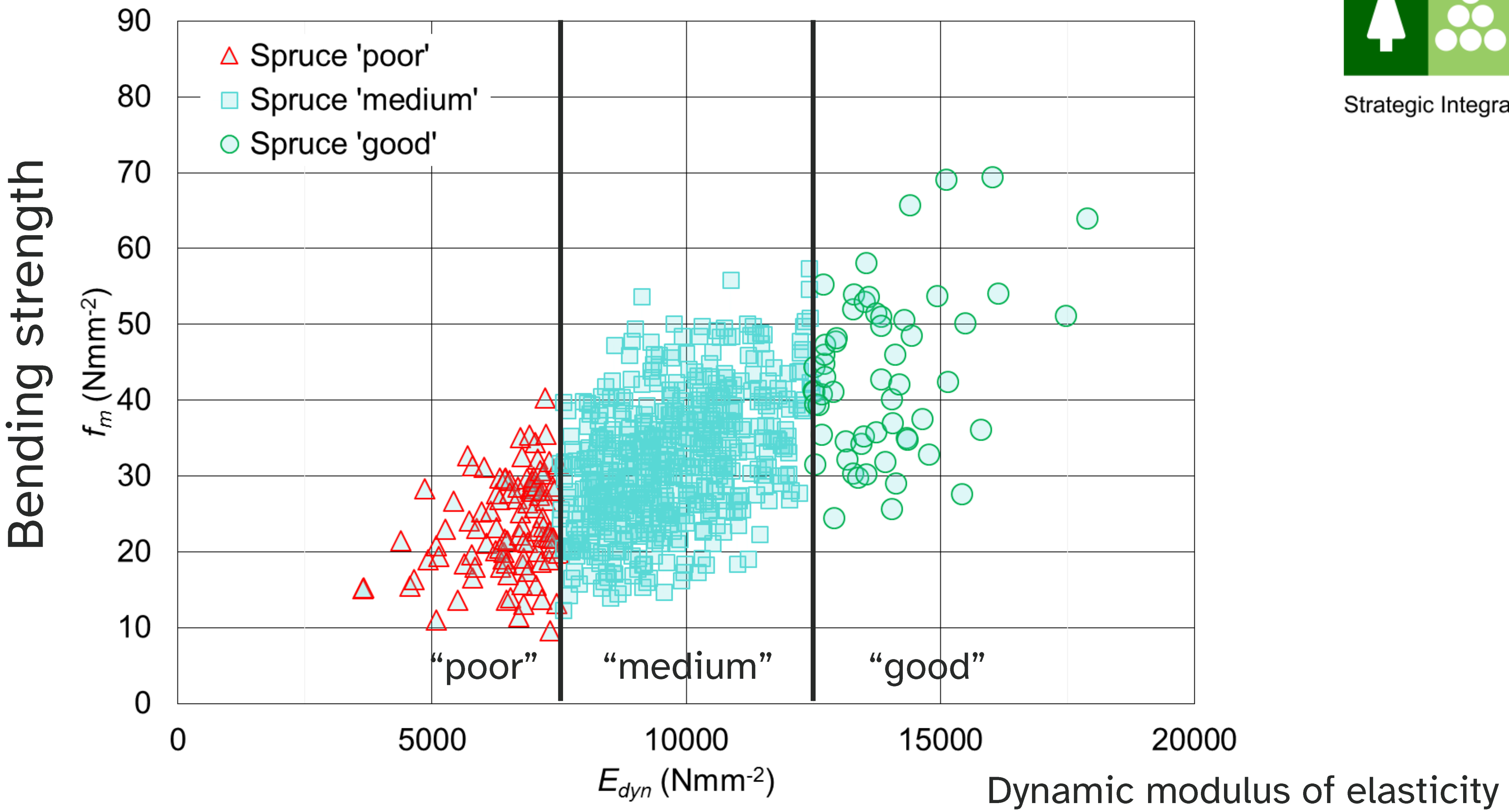

# Knots & bending strength

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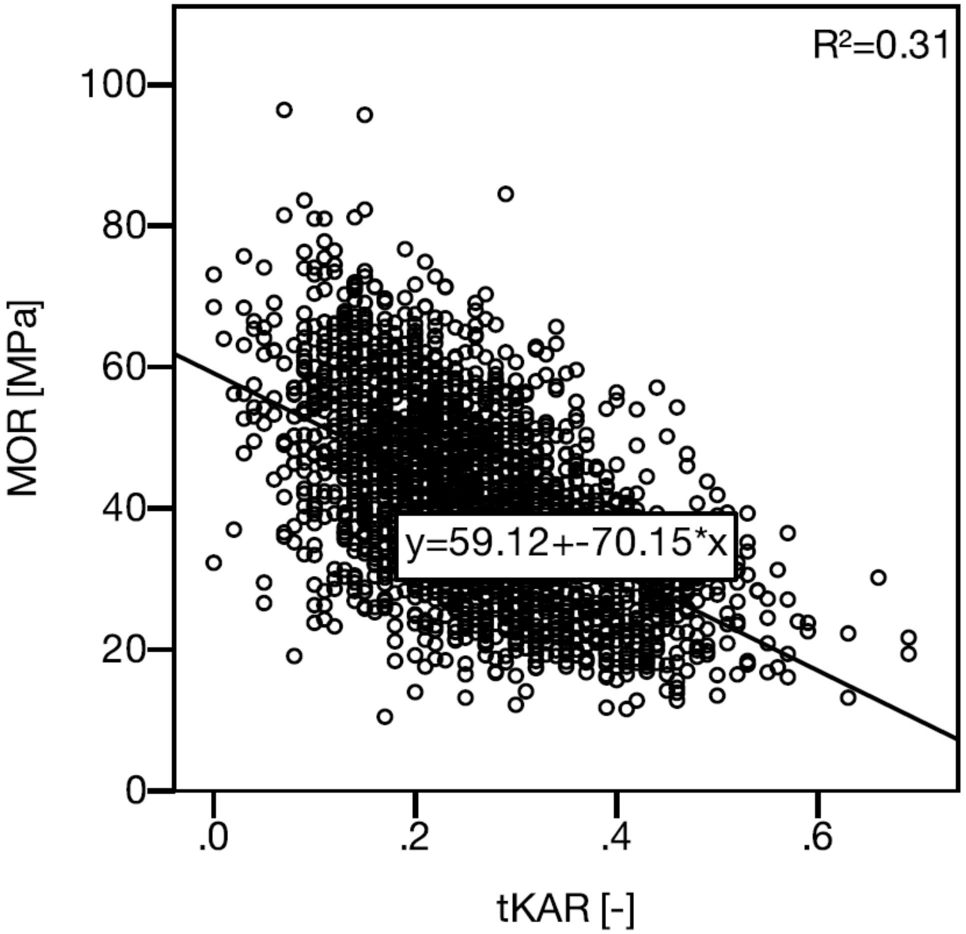
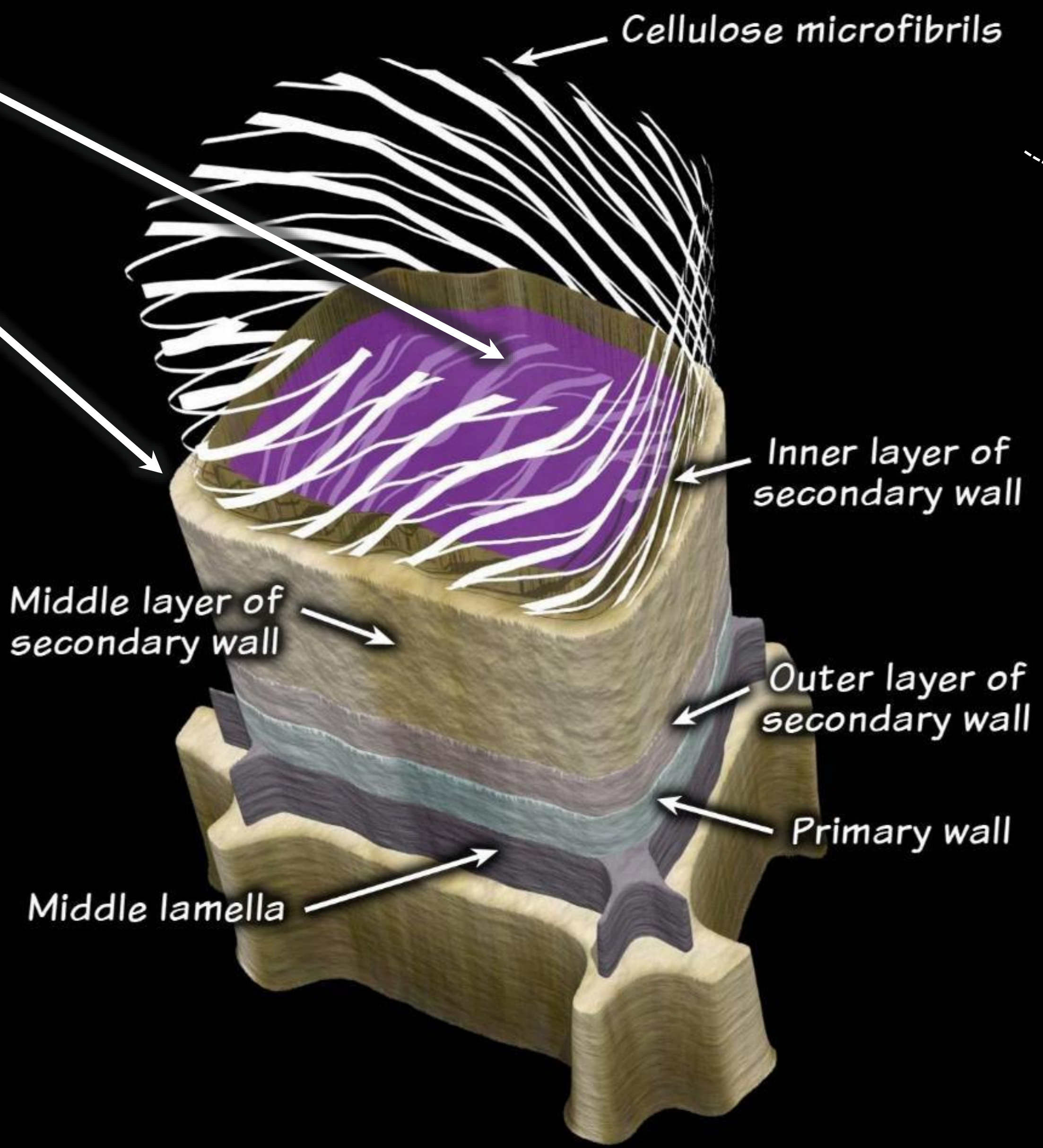
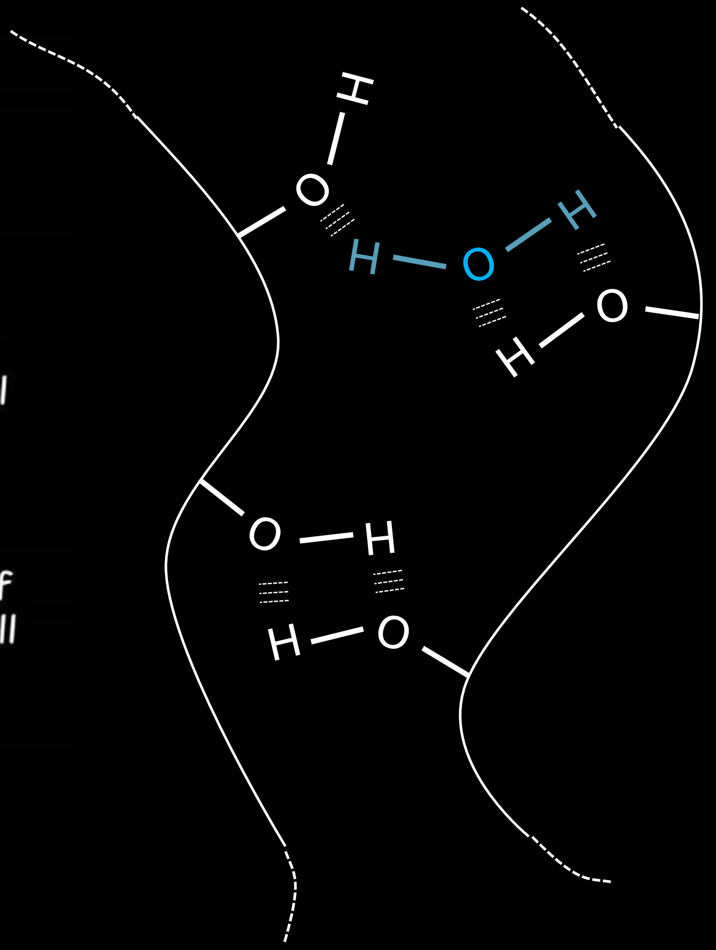



PhD thesis by Peter Stapel, TU Munich. https://d-nb.info/1055039805/34

“Free water”
When mc > ~30%

“Bound water”
Water molecules
in the cell wall



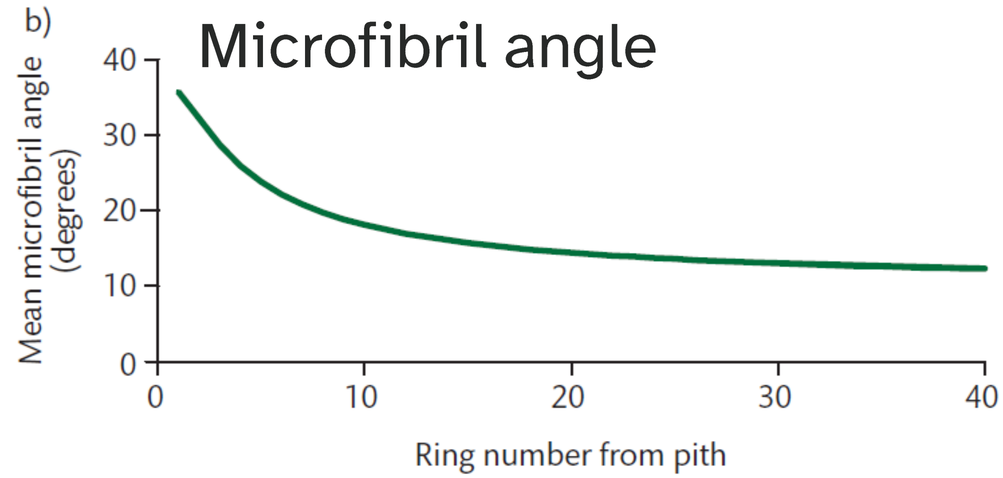
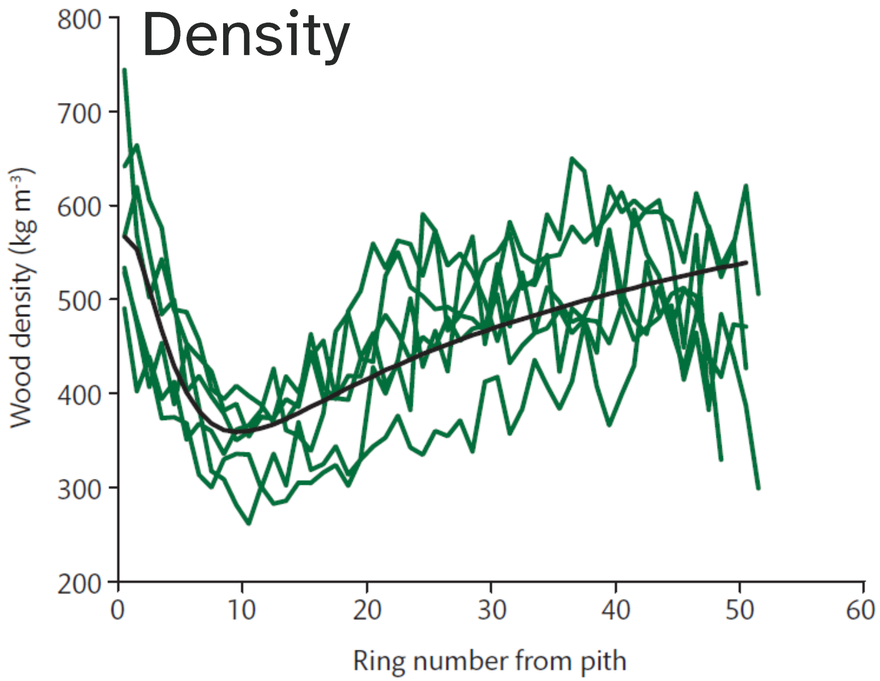
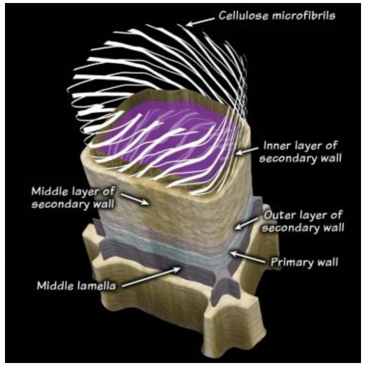



**Figure 2.15** Radial profile of Sitka spruce wood density. The green lines show profiles for five individual trees sampled at Baronscourt in Northern Ireland, while the black line represents a model fitted to these data.

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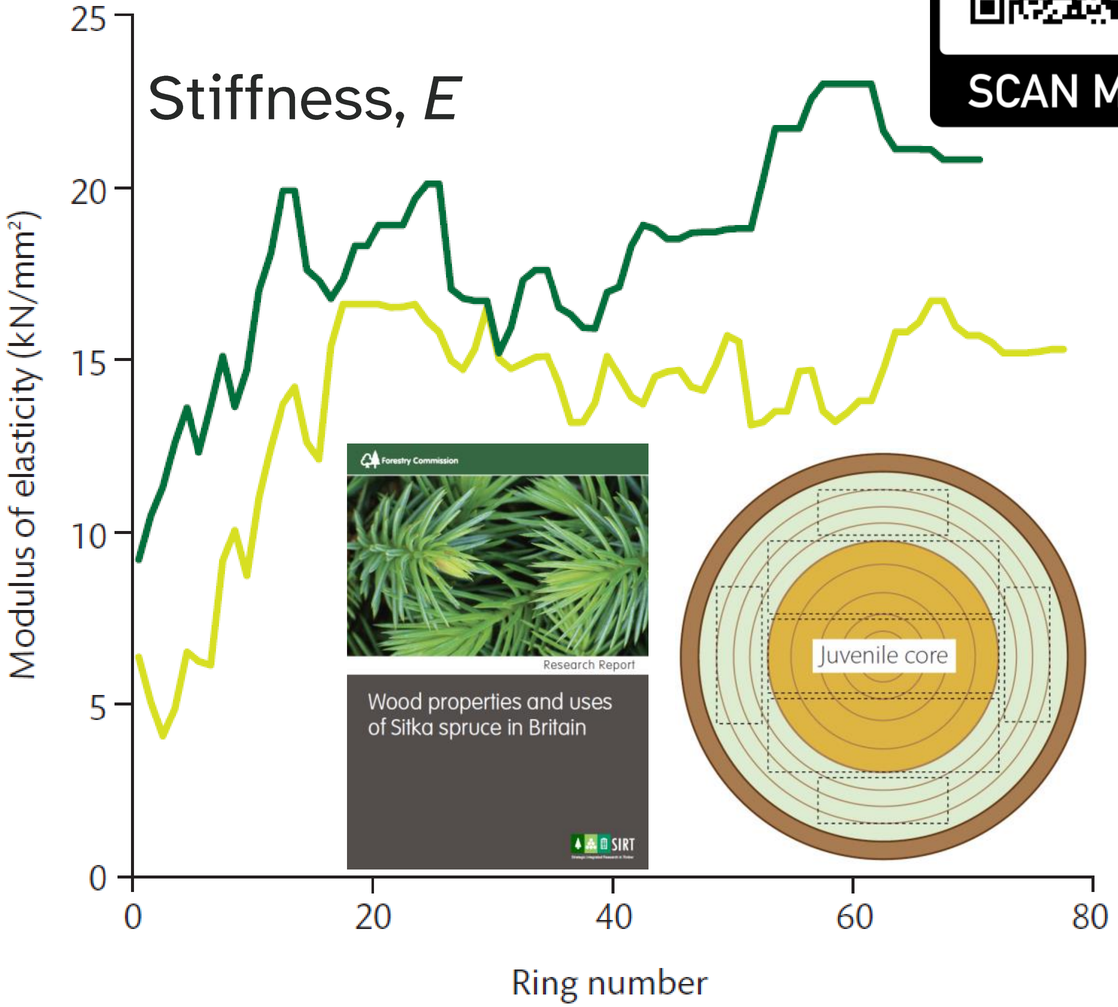

# “Rate of growth”

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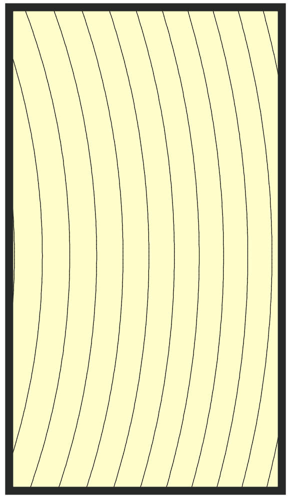
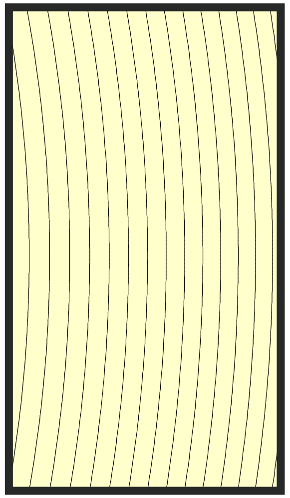
Grew in ~11 years



Grew in ~15 years



# “Rate of growth”

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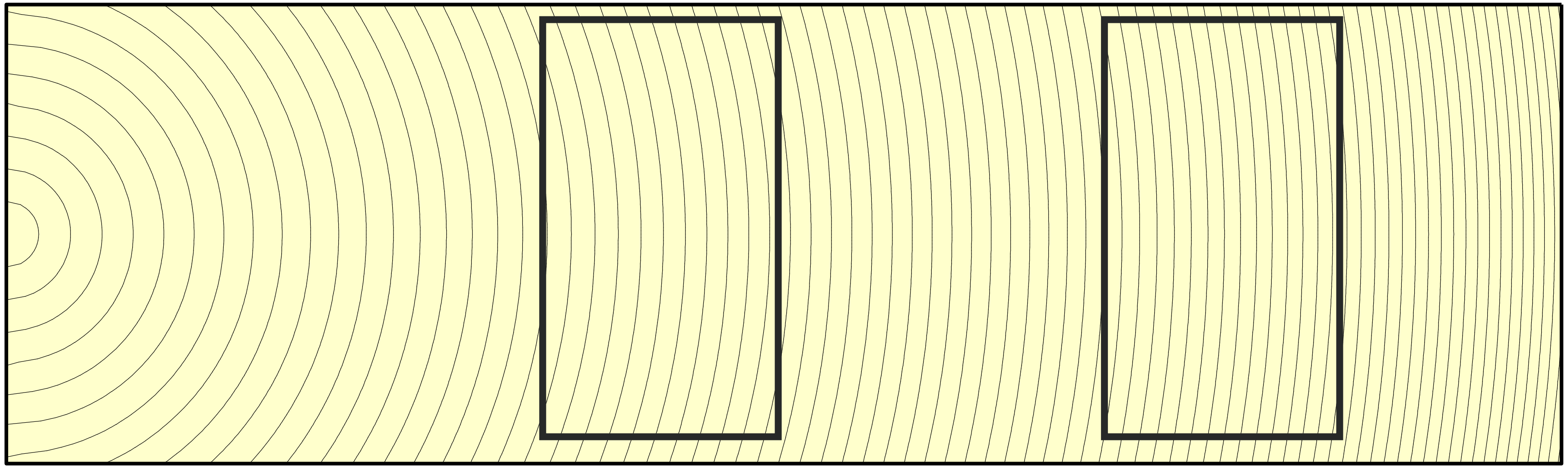
Bigger tree – actually growing faster (more wood) at this point



# Home grown timber grading

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https://doi.org/10.1080/20426445.2022.2050549

INTERNATIONAL WOOD PRODUCTS JOURNAL
2022, VOL. 13, NO. 2, 127–136
https://doi.org/10.1080/20426445.2022.2050549

IOM3 Institute of Materials, Minerals & Mining
Taylor & Francis Taylor & Francis Group

RESEARCH ARTICLE

OPEN ACCESS Check for updates

## Strength grading of timber in the UK and Ireland in 2021

Dan Ridley-Ellis [a]†, David Gil-Moreno [b]‡ and Annette M. Harte [b]

[a]Centre for Wood Science & Technology, Edinburgh Napier University, Edinburgh, UK; [b]School of Engineering & the Ryan Institute, National University of Ireland Galway, Galway, Ireland

**ABSTRACT**

This paper summarises the state of the art for strength grading of construction timber grown in the United Kingdom and the Republic of Ireland. It includes the latest approvals based on recent research on spruce, larch and Douglas-fir. It lists the following information along with the primary references: visual grading grades and strength class assignments; grading machines with approved settings for machine control grading; the species, size ranges and strength class combinations covered; and grade determining properties of specific strength classes for the UK and Irish markets. This paper is useful for those grading timber, and those specifying UK and Irish grown timber.

**ARTICLE HISTORY**
Received 7 September 2021
Revised 29 November 2021
Accepted 1 March 2022

**KEYWORDS**
Grades; classes; machine strength grading; visual strength grading; structural timber; EN14081

### Introduction

In Europe, structural timber is graded under the system set out by the European standard EN14081-1 and its supporting standards (e.g. Lycken et al. 2020). It sorts rectangular cross-section timber into categories based on required characteristic values

exchange timber market with logs crossing the border. This is one of the reasons that modern grading rules usually treat both countries as a single growth area, particularly for Sitka spruce but also more recently for Douglas-fir (Gil-Moreno et al. 2019b) and larch. Collaborative research between Edin-

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view the pdf to be sure the information displays correctly

# Visual strength grading

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- Visually grade to a visual grading standard
  - e.g. SS, GS (softwoods to BS 4978)
- Assign to strength class based on grading standard, species and origin (all three must match)
  - EN 1912
    - e.g. British spruce SS $\rightarrow$ C18
    - e.g. British spruce GS $\rightarrow$ C14
  - Somewhere else (not in conflict with EN 1912)
- New assignments based on testing & analysis to EN 384

# Machine strength grading



- Relates an ‘indicating parameter’ to the critical grade-determining parameter(s)
- Better accuracy than visual grading…
  …due to the parameters being measured
  …and the automation
  …so assignment to grade is less conservative
- Fast but expensive equipment
  (but getting some cheaper options)

# Machine types

- Bending stiffness
  - Bending about the minor axis
- Dynamic (acoustic/vibration)
  - Essentially a measure of stiffness
  - May or may not include density
- X-rays
  - A combination of knots and density
  - Perhaps with optical camera
- Assessment of slope of grain
  - Using laser tracheid effect
- Mixtures of the above


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# Building from England's Woodlands

- WP1 Project management
- **WP2 Wood properties categorisation**
- WP3 Optimised engineered timber products
- WP4 Pilot manufacture and prototype testing
- **WP5 Outreach and education**

Funded by the
**Timber in Construction Innovation Fund**
Woods into Management Forestry Innovation Funds

# Preliminary target species

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- Beech
- Oak
- Birch / poplar
- Sycamore
- Ash
- Willow
- Sweet chestnut
- Alder

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# Thank you!

**blogs.napier.ac.uk/cwst/**

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# Guess the strength

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| | | Today (n= ) Strongest | LinkedIn (n=76) Strongest | Twitter (n=45) Strongest | Twitter (n=42) Weakest | MTG |
|---|---|---|---|---|---|---|
| Scots Pine | MINT | 5th | 22% | 17.8% | 11.9% | 2.0kg 5.1kN/mm$^2$ |
| Scots Pine | LEEK | 4th | Not included | Not included | 59.5% | 2.5kg 4.4kN/mm$^2$ |
| Spruce | KALE | 3rd | 9% | 13.3% | 4.8% | 2.3kg 11.3kN/mm$^2$ |
| Douglas fir | JASMINE | 1st | 34% | 53.3% | Not included | 2.2kg 7.3kN/mm$^2$ |
| Spruce | IVY | 2nd | 34% | 15.6% | 23.8% | 1.7kg 8.1kN/mm$^2$ |