STRATEGIC INTEGRATED RESEARCH IN TIMBER: GETTING THE MOST OUT OF THE UK'S TIMBER RESOURCE

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Abstract: Sitka spruce (*Picea sitchensis*) is the United Kingdom's main commercial tree species accounting for nearly one-third of the UK's total woodland area and half of its conifer estate. Sawn timber from this species readily grades to the C16 strength class, but there are factors beyond the structural grade that can influence its acceptance as a construction material. This paper summarises the results from resource characterisation studies that have investigated the properties of Sitka spruce at the standing-tree scale down to the scale of a few microns. These studies have substantially improved the understanding of the impact on mechanical performance of structural timber of factors at the micro-structural level (e.g. cellulose structure and abundance) and at the forest-level (e.g. genetics, the environment and forest management). End-user requirements for timber are discussed in terms of what is, and is not, provided by current grading practice and some of the main misconceptions about UK-timber are challenged.

Keywords: timber, non-destructive testing, segregation, grading, *Picea sitchensis*

1 Introduction

Although the United Kingdom's forest cover (~12%) is low in comparison to the rest of Europe it still produces enough sawn softwood and panel products to build a typical timber framed house every 30 seconds. However, only one-third of the sawn softwood produced by the UK's larger sawmills is currently sold as construction timber (Forestry Commission 2008) and very little home-grown timber is used in volume house production; particularly the manufacture of timber frames and trussed rafters. Instead, the majority of domestically produced sawn timber is sold into lower value markets (fencing, packaging and pallets), and the vast majority of softwood for house construction is imported from countries such as Sweden, Finland, Latvia, Germany, and Russia (commonly European Redwood: *Pinus sylvestris* and European Whitewood: *Picea abies* and *Abies alba*).

Afforestation in recent years means that UK softwood production is set to increase by 20% from current levels over the next decade (Halsall *et al.* 2005). This is seen by the forest and timber industries as a significant opportunity for the UK construction industry to

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use a greater proportion of home-grown timber (e.g., Optimat 2002), but there are questions surrounding the motivation to do so; some of which are explored in this paper.

The most important commercial tree species in the UK is Sitka spruce (*Picea sitchensis*), a native of the Pacific Northwest of North America that grows well across much of the UK. Its timber readily grades to strength class C16 (CEN 2003a), which, while at the lower end of the range of softwood strength classes, is sufficient for domestic and small-scale commercial construction. While structural grade is important, there are also additional factors that govern its acceptance as a construction material (Section §3.2). Some of these factors are real, while others are based on long-standing misconceptions.

Better knowledge about the properties and performance of UK timber, particularly Sitka spruce, is being generated by the Strategic Integrated Research in Timber (SIRT) project. This collaborative multi-discipline virtual centre is led by the Centre for Timber Engineering at Edinburgh Napier University, in partnership with the Department of Chemistry at the University of Glasgow and Forest Research. SIRT has undertaken a number of different studies to characterise the resource at a range of scales (from molecular to forest), and to understand the influence of silviculture and genetics on the key constructional properties of timber. In particular, significant progress has been made with the application of acoustic-based non-destructive testing for resource assessment and, potentially, resource segregation (§4).

2 A Brief Overview of Timber Construction in the UK

Timber frame construction in the UK is predominantly based on factory-built structural elements made from solid softwood and engineered wood products. New houses of all construction types are relatively small for a developed country (average ~80 m^2, Federcasa 2006) and thermal and acoustic regulations are becoming increasingly strict. This means wall thickness and floor depth tend to be governed more by thermal and acoustic performance than by the strength and stiffness of the structural elements. Timber trussed rafters are very common for houses of all construction types.

Around 25% of new house starts in the UK are timber frame and the market share is continuing to grow through a major downturn in the building industry (UKTFA 2009). In Scotland, which has around 65% of the UK's conifers (Forestry Commission 2008), the share is approximately 75%, but paradoxically, the market penetration for home-grown timber in the timber frame market (less than 5%) is actually lower than the penetration for brick and block construction (~15%) (Optimat 2002).

3 The UK's Sitka Spruce Resource

3.1 Background

Plantation softwood production has historically been concerned with maximising volume by growing trees quickly, and sawing to recover the highest volume of timber from a log. However, growers and processors now realise that this approach does not recognise the true requirements of end users, and hence the economic value of the timber. Affecting change is not straightforward, partly because the influence of silvicultural practice on wood properties is not fully understood, and partly because end user requirements are not well communicated along the supply chain.

Previous research in a range of species has shown that genetics, silviculture (i.e., initial planting spacing, timing and intensity of thinning, pruning, rotation length, fertiliser application), and site conditions (i.e., exposure, temperature, rainfall, and soil type) all affect wood properties. Similarly, it is known that the properties of wood naturally vary within a tree in both the vertical and radial directions. Such information is important for both growers and processors who wish to manage their production for improved timber quality, but the big question is 'What is meant by quality?' The following sections outline the main observations drawn from research carried out within SIRT.

3.2 Perception

There is a common, long-standing, perception within the UK's timber building industry (often not based on actual experience) that home-grown timber cannot meet their requirements. The concerns most frequently expressed are:

- Think: Inconsistent or unacceptable dimensional stability and distortion.
- Think: The knottiness of UK-timber is too great.
- Think: Poor price competitiveness against imported timber of equal or better grade.
- Think: UK-grown C16 contains less higher 'quality' material than imported C16.

Dimensional stability and distortion are certainly important issues for factory prefabrication, as is knottiness. EN14081 (CEN 2005) places limits on twist, cup, spring and bow within the list of the 'visual override' criteria (across all grades). However these may be too lenient for some end-users. If timber has been strength graded, the knots are not an issue for strength and stiffness, but they may still cause problems for nail fouling and finger-jointing. Nevertheless, anecdotal evidence from trials of UK-timber by timber framers who normally use imported timber indicates that these problems are not as bad as people expect them to be (e.g., Reynolds and Cornwell 2004), and it may also be possible to improve the characteristics of UK sawn timber through changes in silviculture and processing. These issues of timber 'fitness for purpose' are not unique to UK timber and COST Action E53 has conducted a survey of end user needs across 25 European States in order to better understand the situation. Preliminary results for the UK (albeit on a very small sample size) suggest that those involved in construction with timber rate spring, bow and twist as more important than strength, stiffness and density (Figure 1), and that companies routinely perform a manual inspection of the timber for distortion and knots.

Rejection of timber by the builder or pre-fabricator is undesirable because it reduces efficiency and produces waste with a disposal cost. Rejection of timber by the sawmill is less costly overall and rejects can still be diverted to co-product markets with some financial return. This is an argument for sawmills to increase the stringency of grading, perhaps over and above the limits laid down by current standards. An even better solution would be to be able to grow and process timber to reduce the proportion of rejects, or at least be able to identify the timber with the highest likelihood of being rejected before processing costs are incurred (§4). The COST E53 survey suggests that the purchase price of timber is less of an issue than its properties (Figure 1); especially those properties governing fitness for purpose.

The low price differential between home-grown C16 and imported C24 is, nevertheless, an important factor for sawmills. Many design specifications now call for C24 timber as a matter of routine but this is rarely for reasons of strength or stiffness. In fact over-specification is also becoming a problem for importers as supplies of C24 come under increasing pressure (e.g., TTJ 2009).

3.3 The Growth-rate Confusion

It is very common for people to think that UK timber 'grows too quickly' and the muddled concept of growth-rate is a particular problem for the communication between end users and sawmills. For the engineer, the rate of growth is the width of the annual rings (e.g. British Standards 2007 & CEN 2005). This describes the rate at which a piece of sawn timber was grown by the tree, but not the rate at which the tree was growing because rings close to the pith represent less stem biomass accumulation than rings of the same width further out. In actual fact, the rate of growth *per se* is a poor indicator of strength and stiffness and this ring width ‘growth-rate’ measurement is more of a surrogate for distance from the pith (or cambial age). Conifers tend to produce stiffer, stronger and less knotty wood as they get older and in reality the main difference between UK-grown and imported timber is the age at which the trees are harvested. UK softwood forestry tends to work on a rotation length of ~45 years while in Sweden, for example, conifers are typically harvested at twice this age. This is exacerbated by the tendency of Sitka spruce to have a relatively large juvenile core, which contains wood that is of lower strength and stiffness with a greater propensity to warp. The current rotation lengths and sawmill cutting patterns mean that UK sawn timber contains a high proportion of juvenile wood and that is one of the main explanations for the grade determining characteristics of UK timber.

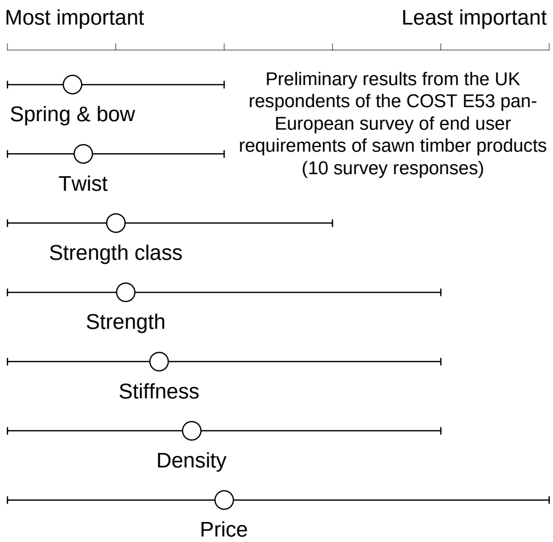

Figure 1: Importance of characteristics for builders and prefabricators

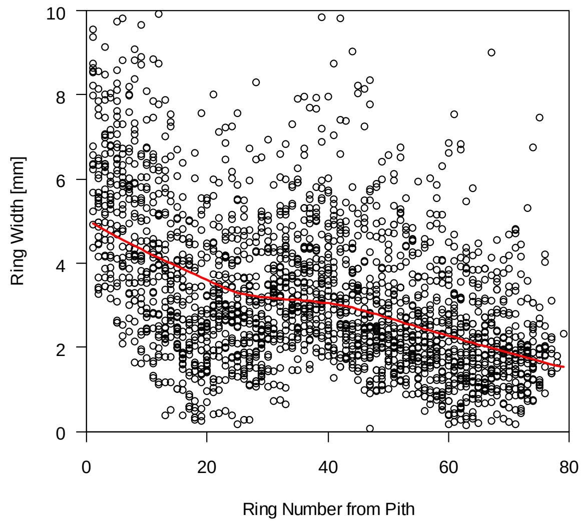

Figure 2: Ring width (‘rate of growth’) and cambial age (ring number)

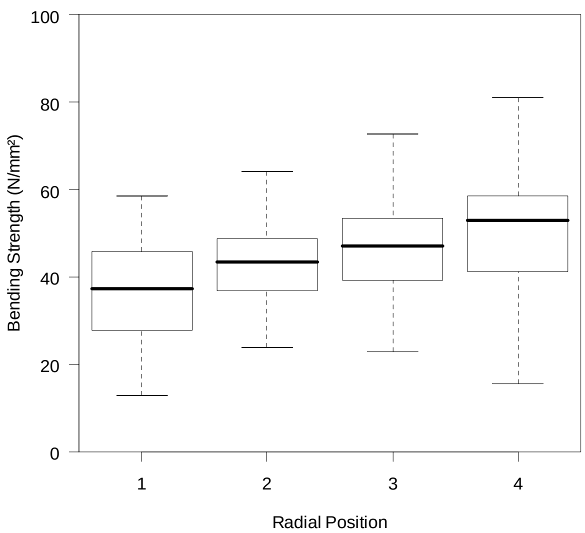

Figure 3: The effect of radial position on bending strength (1 is closest to the pith)

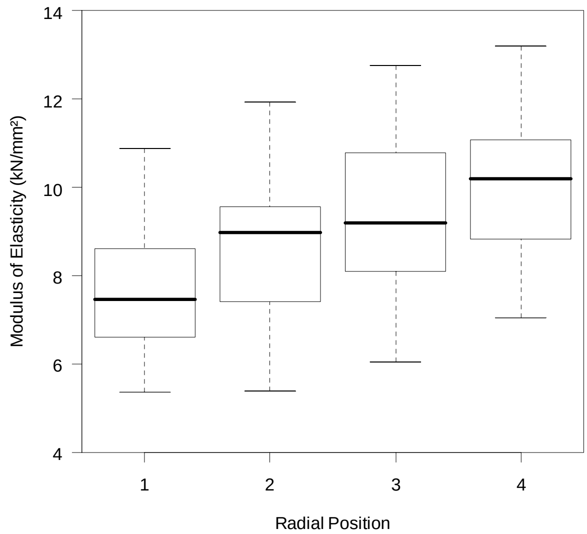

Figure 4: The effect of radial position on bending stiffness (1 is closest to the pith)

3.4 Regional Variation (the Benchmarking Study)

This study was initiated to gain an overall understanding of the variation in the wood properties of harvest-age (i.e., 35-45 year-old) Sitka spruce stands throughout the UK providing information about the effects of selected environmental and management factors (Moore *et al.,* 2009a). To date, 64 sites have been selected on the basis of elevation, latitude, longitude, yield class, initial planting spacing and whether or not the stand had been thinned. At each site, ten trees were randomly selected and the dynamic modulus of elasticity of the wood in the standing tree was predicted from stress wave velocity.

Predicted dynamic modulus of elasticity of the 640 trees assessed in this study ranged from 3.8 kN/mm^2 up to 12.3 kN/mm^2. The majority of this variation (55%) was due to differences between individual trees within a site, although differences between sites were also found to be important (35%). The remaining 10% of the variation was due to differences between measurements made on the north and south sides of each tree. Stem straightness (a commonly used measure of stand quality) and dynamic stiffness were found to vary independently. Analyses of site-level data indicate that wood stiffness is influenced by yield class (a volumetric measure of growth rate), elevation and initial spacing, as well as by the interactions between other factors.

3.5 Genetics (the Kershope Progeny Trial)

This study, led by Forest Research, compared the wood properties of four different 37-year old Sitka spruce 'treatments' (Mochan *et al.* 2008). Three of these treatments contained first generation half-sibling progeny of selected 'plus trees' (trees with superior vigour, straightness or branch characteristics) while the fourth contained trees grown from unimproved seed collected from the Queen Charlotte Islands, Canada. Timber from all four treatments was destructively tested in four-point loading according to EN408 (CEN 2003b) to determine modulus of elasticity and bending strength.

A variance components analysis (Table 1) revealed that less than 1% of the variation in wood stiffness was actually due to differences between the treatments. In fact, most of the variation was attributable to differences between individual pieces of timber within a log and between individual trees within a treatment. The remaining variation was due to differences between replications of the treatments within the experiment. Similarly, there was no difference in strength observed between treatments, but, as expected, a moderate correlation was found between strength and stiffness. There was a statistically significant difference in wood density between two of the treatments, but again, most of the variation in this property was within logs and between trees within a treatment. As expected for this study, which had conditions similar to current commercial forestry practices, the timber met the requirements for the C16 strength class (CEN 2003a, CEN 2004).

Table 1: Sources of variation in selected properties of structural timber

Property	***Between treatment groups***	***Between trees within a treatment group***	***Within a log***
Density	4.1%	41.0%	50.8%
Stiffness*	0.6%	38.4%	50.5%
Bending strength	<0.1%	49.4%	47.3%

* Figures are quoted for static global modulus of elasticity

The high level of tree-to-tree variation is likely to be due in part to the fact that trees in each treatment were half-sib (i.e., known mother and unknown father) and hence there will be a combination of genetic variation and micro-site differences. This suggests that there is considerable scope to improve wood quality through tree breeding, provided that the characteristics of interest are moderately heritable. The UK's current tree-breeding programme has focussed on increasing density, reducing branch size and improving stem straightness as the main means of improving wood 'quality' (Lee, 1999), but strength and stiffness would also be useful targets. Indeed microfibril angle (the angle of cellulose chains in the cell wall; a driver of wood stiffness) in juvenile wood has been be shown to be significantly heritable (Donaldson and Burdon, 1995).

However, there must be caution with tree breeding programmes as those mechanical properties associated with strength classes that are inferred (from density, bending stiffness, and bending strength, CEN 2004) may not change in proportion. For example, (Khokhar *et al.* 2008) found that shear properties are not as well correlated to density and bending stiffness as is often assumed.

3.6 Pre-commercial Thinning (the Baronscourt Re-spacing Trial)

The width of annual rings laid down by a tree (hence log diameter and size of the juvenile core), and branch size (hence knottiness) are influenced by the competition for light from neighbouring trees. This study, led by Forest Research, examined the effect of early thinning on wood properties and timber performance of Sitka spruce. The experiment consisted of five different re-spacing treatments (5.6 m, 4.6 m, 3.7 m, 2.6 m and an un-thinned control at 1.9 m), and was felled when the stand was 57 years old. Fifteen trees were sampled from each spacing for study (3 from each of 5 plots).

As with the Kershope and benchmarking studies (§3.4 & §3.5), considerable variation in the properties of structural timber was found between trees within a treatment and within the trees themselves. Despite this, significant differences in static modulus of elasticity and bending strength were found between thinning treatments. Both stiffness and strength decreased with increased spacing. The timber from the un-thinned control treatment had characteristic strength and stiffness values sufficient for the C18 strength class, while trees in treatments at a spacing of 3.7 m or wider produced more timber, but this failed to meet the requirements for C16.

3.7 Rotation Length (the Birkley Wood Study)

Typical rotation lengths for commercial Sitka spruce stands in the UK are between 40 and 50 years. At this age the juvenile core comprises a significant proportion of the volume of harvested log and an even larger proportion of the converted sawn timber. In conifers this juvenile wood generally has poorer mechanical properties than wood formed when the tree is older, and also has more tendency to distort, especially with respect to twist due to a higher than average spiral grain angle (e.g. Johansson *et al.* 2001).

In this study, thirty 83-year old Sitka spruce trees were sampled and the properties of timber cut from consecutive radial positions within a log were compared. Ring widths were measured and illustrate the tendency of the ring width 'rate of growth' measurement to be an indicator of radial position (Figure 2, *cf*. §3.3). A substantial increase in bending strength (Figure 3) and stiffness (Figure 4) was observed with increasing distance from the pith. Timber sawn from near the outsides of logs met the requirements for the C24 strength class, while timber from the centre could only meet C14.

This result shows that it is technically possible to grow C24 Sitka spruce in the UK, but the increased rotation length may not make it economically feasible to do so. After 50 years or so, plantation conifers like spruce and pine slow in growth producing a smaller volume of new timber each year. However, this timber is of higher commercial value, having better mechanical properties, reduced knottiness, and lower tendency to distort. It is recommended that forest management plans take into account this higher timber value to see if it offsets the delayed realisation of revenue and greater risk of wind throw.

4 Resource Segregation and Cutting Strategies

The most immediate opportunity for improving the profitability for growers and processors, and therefore timber prices, lies in segregation. Stands (and possibly trees) that are unlikely to produce an economically acceptable outturn of structural-quality timber could be identified and diverted to other non-structural end uses; conversely the sale of structural quality timber for low value uses (such as the rapidly growing biomass market) could be avoided. Through SIRT it has been shown that non-destructive tools produce reasonable predictions of the static bending stiffness of sawn timber from measurements made on freshly felled logs, and even standing trees (Moore et al., 2009b).

Research to map wood properties within a tree (e.g., McLean 2008), has shown that, in Sitka spruce, the juvenile wood has low stiffness, but not proportionally low density, meaning density on its own is a poor indicator for structural grade. It was also found that 'root-wood' with low stiffness extends for a considerable distance above ground level so that butt logs are affected. It may therefore also be useful to segregate wood within the tree by removing more of the butt during harvesting and altering sawmill cutting patterns so as to avoid using the centre of the tree for structural timber.

5 Concluding Remarks

SIRT has made significant progress in understanding the nature and variability of the wood properties of UK-grown Sitka spruce. It has been shown that, with appropriate tree breeding, silviculture and segregation, it may be possible to produce C24 grade material, or at least C16 timber with improved characteristics. It is unlikely that home grown timber will be commercially viable for all structural timber requirements for house building but it is viable for many. With the increasing popularity of 'room-in-the-roof' construction it seems that the trend for trussed rafters is for higher-grade timber to reduce construction depth. However, C16 timber has perfectly adequate mechanical properties for typical timber frame construction where wall thickness and floor depth are more governed by thermal and acoustic performance than they are by strength and stiffness.

The main issue with UK-grown timber does not appear to be simply its strength grade *per se*. and there needs to be improved communication between growers, sawmills and the construction industry to ensure that the interests of the end user are truly represented by what is defined by structural grades, and growers know what properties to target.

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