Resilient Forests Research Programme

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Technical Note

PQSim: Architecture and Applicability

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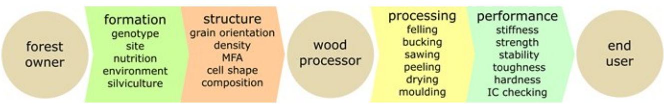
Summary: The purpose of PQSim, its structure, sporadic evolution, historical studies linked to it and its unique features and alternative approaches have been reviewed. PQSim is an approach that uses simulation to relate forest management to product quality. It is a set of numerical modelling tools that can predict end product performance based on sufficient descriptions of stem size, shape and internal wood property patterns. The discbot system was built to collect the input data needed for PQSim. PQSim is currently capable of addressing a wide variety of questions relating to the production of structural timber. Given the demonstrated functionality of the Discbot system and the analytical pipeline it is now time to resurrect PQSim and apply its potential to some of the key questions that need answering.

Background

'PQSim' (**P**roduct **Q**uality **Sim**ulation) is the name, coined by Wayne Miller in the mid 00's, for a conceptual approach to relating forest management to wood processing. Essential aspects of this approach include:

- Explicit spatial descriptions of individual (though not necessarily 'real') trees, logs, boards, etc.
- Physically based simulation of the processes by which products are created and the characterisation of the performance of these products.

Work on implementing this approach was begun by WQI (Harrington, 2003), and while applicable to a wide range of products and performance measures, work to date has focussed on the stiffness and stability of timber due to their economic significance.



The PQSim approach is applicable to a wide range of scenarios, including for example:

- relating forest management decisions to product recovery (and hence processing profitability)
- quantifying the yield of a new product from an existing resource
- optimising the recovery of products at breakdown, for example by overlaying probable internal wood property maps on measured log shapes and computing optimal cut patterns.

The PQSim approach makes use of the following capabilities:

1. Generation of stochastic tree descriptions that:
    a. Describe individual trees rather than average trees
    b. Describe external (shape, size, branching) as well internal (wood properties, wood defects) characteristics
    c. Describe internal wood property variation in space as well as with tree age
    d. Respect the correlations that exist between different properties and between different points in space, both within and between trees. (e.g. shape/compression wood occurrence, microfibril angle/grain orientation/density)
    e. Are constrainable based on measurements in hand (e.g. DBH)

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2. Estimation of the material properties required by the governing physics (e.g. stiffness and shrinkage tensors) from the the wood quality measurements that can be made (E.g. density, chemistry, microfibril angle and grain orientation)
3. Process & product evaluation simulation, including:
    a. Primary breakdown (felling, bucking, primary sawing, peeling, chipping)
    b. Drying (sawn timber, veneer, felled logs, dead standing trees)
    c. Drymill & Remanufacturing (planning, grading, resawing)
    d. In service (warp, creep, delamination)
    e. Degradation (sap stain, rot, termites)

These capabilities are realized in software modules that can be invoked on an individual basis or can be chained together to carry out more complex tasks. Figure 1 shows an example of such a chain. Not all capabilities are required for every scenario. Most capabilities are implemented by multiple modules which differ in detail (e.g. physical sophistication, amount of input data required, computational cost). Communication between modules takes place via well-defined interfaces and makes use of spatially explicit product descriptions. If a particular chain proves useful, PQSim's architecture makes it a relatively simple matter to bundle the modules used together with a suitable user interface and distribute as a user application.

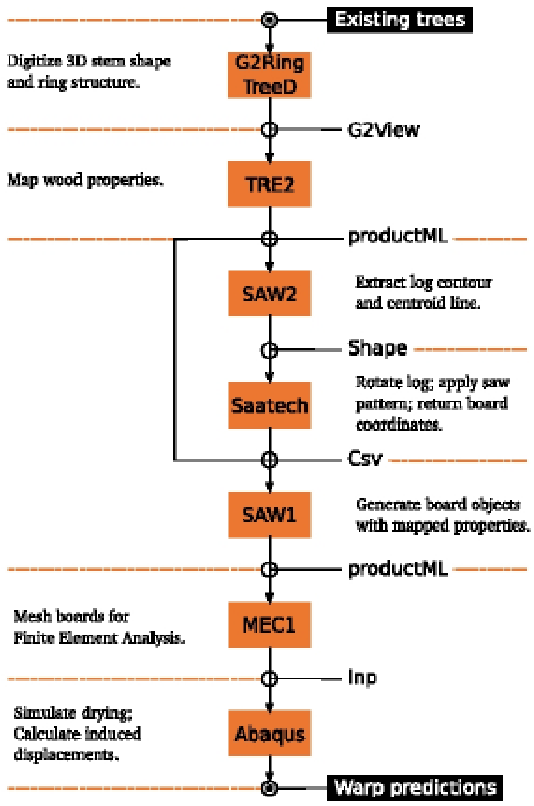

Figure 1. From existing trees to stability predictions: the modelling framework (Sellier *et al*. 2007)

PQSim's capabilities build on earlier work done at Scion and elsewhere, for example:
- STANDQUA (Tian and Cown 1995)
- Sawing simulation, e.g. AUTOSAW (Todoroki 1990)
- Lumber drying models (Shusheng 2000)
- Wood micromechanics and cross-property relationships (Harrington, 2002)

PQSim has been applied to problems including:
- Green and dry lumber segregation based on predicted stability (WQI). Based on precise measurements of the stiffness and shrinkages of subsamples, board stability was predicted using the finite element board evaluator.
- STANDQUA (a set of average tree wood property models; Tian 1994a, 1994b) and compression wood maps were combined to generate tree descriptions that were then virtually sawn and the stiffness and warp of the resulting boards were predicted (Sellier 2007, Pont 2007). Both studies concluded that using average tree descriptions resulted in unrealistic product performance, and that more realistic results were obtained when individual 'noise' from the compression wood maps was included.
- Value Chain Pilot Study. FFR (West 2008). PQSim was used to evaluate the stiffness and warp of boards from two different silvicultural regimes. Cabala, Forecaster and BLOSSIM were combined to generate the tree descriptions for input to PQSim.
- Dowling (2011) conducted a usability study for FFR and used stem piece files from Forecaster as input for PQSim and predict warp and stiffness of the sawn boards.
- Product Quality Validation Study. FFR, 2011-2013. PQSim was successfully used to predict the behaviour of boards sawn from 100 trees based on detailed maps of 20 different trees, of the same genotype grown on the same site, made using the technologies that have since been integrated into Discbot, Scion's rapid stem phenotyping robot.

West *et al*. (2013) attempted to prepare a Product Quality Prediction (PQP) Business Case. They concluded that PQP could add $800m annually by way of improved valuation and sawmilling, a modest but not inconsiderable gain. However, it was recommended that further work is needed before a sound business case can be made. Despite this, and based on the PQPV results, Scion committed to developing the Discbot in order to enable cost-effective collection of the data required to underpin the generation of realistic tree descriptions central to the PQSim approach.

Alternative Approaches

In contrast to PQSim there are other routes to understanding how tree growth and product performance interact.
1. Empirical models.

- Grow trees, cut them down, measure the resulting recovery/quality, embed results in a simple 'statistical' model. E.g. SawMOD (Whiteside and McGregor 1987)
    - Best approach if the number of options/variables are limited and the overall system (including demand) is stable.
    - Accurate if interpolating. No ability to extrapolate.
    - Hopelessly expensive in the face of uncertainty/variability/instability or if answers are needed in less time than it takes to grow the resource or if the production process does not already exist.
2. Expert opinion.
    - Train people. Have them evaluate GxExSxP options based on their knowledge and experience.
    - Great if (a) suitable expertise exists (and really know their stuff), and (b) the complexity/uncertainty is low and the contrast between options is high (i.e. it'll either work really well or dreadfully, not that an option might improve by 1%)
    - Not so good when detailed quantification required.

In reality the best decisions get made when both approaches are brought to bear.

Strengths and Weaknesses

An assessment of PQSim requires consideration of the approach as well as the current implementation. Context is also important:

- The large scale, essentially monoculture, nature of NZ forestry means (a) a 'simple' (compared to say North America or Europe) set of species, silviculture, processors and products to be considered and (b) even small gains are worth pursuing.
- Radiata pine plantation forestry has been intensively studied and the outstanding problems are complex. The PQSim approach makes less sense for species or regimes that haven't already been intensively studied in aggregate than for those that have. The PQSim approach is applicable to problems encountered at multiple points along the value chain, (supply chain planning, forest management, recovery optimization etc.). While each of these problems differs in detail, the underlying tools required to address them have much in common. This shared interest utility justifies more development effort than would otherwise be the case.

Approach

- PQSim gives specific answers to specific questions. It is not good at answering vague questions. Like all simulators (but unlike empirical models) it will happily return rubbish answers to ill posed questions (garbage in, garbage out).
- Computationally intensive. While this might seem like a weakness, it is much easier and cheaper to buy computing power than human expertise.
- Highly parameterized. This is a strength in that it allows flexibility, but also a weakness since many parameters need to be set (some of which have significant impact, other of which do not). Identifying which parameters can be automated however (at the cost of extra computational resources).
- Interpretability. Unlike black box machine learning techniques, PQSim's mechanistic nature does allow introspection and can shed light on why outcomes follow from inputs. But, like reality, untangling these mechanisms can take a lot of work.
- Development requires domain specific expertise. Unlike empirical approaches, developing a PQSim module requires in-depth knowledge of the process being simulated. This is a bad thing if expertise is scarce but is a good thing in that the development process embeds knowledge and makes it available to others.

Implementation

- The current code base is fragmented, written in a multiple languages (C++, Python, C#, Pascal), and inconsistent in its documentation and style. In numerous places, the prescribed interface between modules has been only partially implemented.
- In part this lack of cohesiveness can be attributed to requirements and system architecture changing over time as understanding develops, but it is also a consequence of being developed intermittently, funded by diverse organizations (WQI/SWI, FFR, Ensis/Scion) on minimal budgets extended over a decade (2003—2013).
- Lack of high level documentation. While there is considerable mid- and low-level documentation embedded in the code and associated material, PQSim documentation is fragmented, scattered and short on overview.

Application to Historical Datasets

In the past Scion, and NZ Forestry, has invested significant effort into understanding patterns of variation within and between trees and the influence of genotype, site and silviculture (RA2.1.1B Technote, Review on Wood Property Models). These 'average tree' patterns are substantial achievements, and models based on them are well known and generally available, e.g. via Forecaster. However, when fed into PQSim, average tree models result in poor quality predictions for products whose performance depends as much on how the wood quality within them varies as on the mean value, as is the case when evaluating the stiffness, stability and strength of lumber. A major reason for this failure is the lack of realistic intra- and inter stem variation typically caused by non-shared environmental factors.

Scion's Discbot system exists to collect the data required to understand this missing aspect of variation. (RA2.1.3B, Discbot Sampling Strategy presentation). One way to make use of the Discbot data is to use it to stochastically perturb the overly consistent predictions from average property models, effectively restoring statistically credible 'noise'.

Conclusion

The PQSim approach is capable of quantitatively addressing problems of interest to the forest industry and has been shown to produce reasonable results.

To date considerable, if somewhat piecemeal, effort has gone into in implementing the PQSim approach. In particular, Scion's Discbot is now beginning to deliver the data required to characterise a critical, and hitherto underrepresented, facet of wood variability.

Future development should be guided by the needs of industry, and the nature of the questions for which answers are sought.

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