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EFORWOOD

Tools for Sustainability Impact Assessment

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Draft concept for mapping of properties of forest resources for classification of wood from a product perspective

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CO	Confidential, only for members of the consortium (including the Commission Services)	

Partners involved and acknowledgement

This report, deliverable D3.1.3, has been produced within EFORWOOD workpackage 3.1 “Quality Assessment and Allocation” by Sven-Olof Lundqvist, Thomas Grahn and Lars Olsson of STFI-Packforsk. In the report, a generally applicable concept is described for the mapping of properties of forest resources and for the building of Regional Resource Databases. The concept is based on results from previous long-term research and development of STFI-Packforsk within projects of the "cluster research programme", funded by a group of pulp and paper companies. The tools for modelling and simulation used have been developed previously in clusters and contract work performed by STFI-Packforsk for different customers. In the EFORWOOD project, the concept has been developed to make it easier to apply also in situations when large sets of inventory data are not available.

The authors acknowledge all companies and funding organisations for their support to the previous and current development.

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1. Summary

A concept for mapping of properties of forest resources has been developed. “Regional Resource Databases” are built with information about stands, trees and properties of trees as well as parts of trees of industrial relevance: logs, chips, sawn goods, etc. Such information, together with knowledge about the raw material demands of products and processes, is very important for improved allocation of wood, to supply different industries with more uniform and suitable raw materials for specific products, within the constrains set by availability, logistics, economics, etc.

The starting points in the building of a “Regional Resource Database” are inventory data for the forest resource of interest and a set of integrated models for the wood species and properties to be included. The approach has previously been used by STFI-Packforsk for generation of detailed property data from large sets of inventory data. Such data may not be at hand for all regions and species of interest in the EFORWOOD project. The concept has now been modified to make it more generally applicable. The EFORWOOD version does not go to the same depth of detail and it uses inventory data from limited numbers of stands and trees, selected to represent the resource.

2. Introduction

A wide spectrum of products of major importance for the society is manufactured from wood. Products from wood are part of the culture in many countries around the world. But wood is also a renewable raw material for the production of modern materials with new functionalities, which opens up for new sound solutions from a sustainability perspective.

As a material, wood shows a large variety in properties, between wood species and clones grown in different regions, forest stands of various growth conditions, individual trees in stands and parts of trees. This variety means that it in principle is possible to find wood with properties matching a broad spectrum of specifications for different products and processes, if economically feasible. But it is also a weakness of wood as a material. Unwanted property variations lead to losses in yield, production efficiency and difficulties with product quality. Therefore, the industry prefers raw materials with uniform and predictable properties. This is not possible to fully achieve when wood is used. But part of the property variations is possible to predict. A current challenge of forestry and the forest based industries is to develop better procedures to predict properties of stands, trees, logs and chips and to allocate the harvested wood optimally to different mills and products. Optimal allocation will mean that some variations have to be accepted to keep costs, transportation, etc at reasonable levels. Therefore, it is also important to provide the mill with information about the properties of the wood supplied, to support efficient operation and product quality.

2.1 Examples of property variations and product effects

For solid wood products, the need for allocation of proper material is often obvious: The logs may not be too small or crooked compared to the solid wood piece to produce. The knots may not be too many or too large, depending on the specifications of the product. Products for constructions have to fulfil mechanical standards, materials which will be visible have to look well, etc. For pulp and paper products, the demands may not be as obvious. Therefore, an initial example will be shown.

Figure 1 illustrates the within tree variation in a spruce tree of the basic fibre dimensions: length, width and wall thickness. The variations are simulated with models, more about that below. The green rectangles close to the top of the tree indicate what will typically become pulpwood. The fibres in this part of the tree are typically short, slim and thin-walled compared to those in sawmill chips from the outer part of the sawlogs, indicated with red rectangles. This means that the fibres from pulpwood typically are smaller and that pulpwood will supply more fibres per gram than sawmill chips.

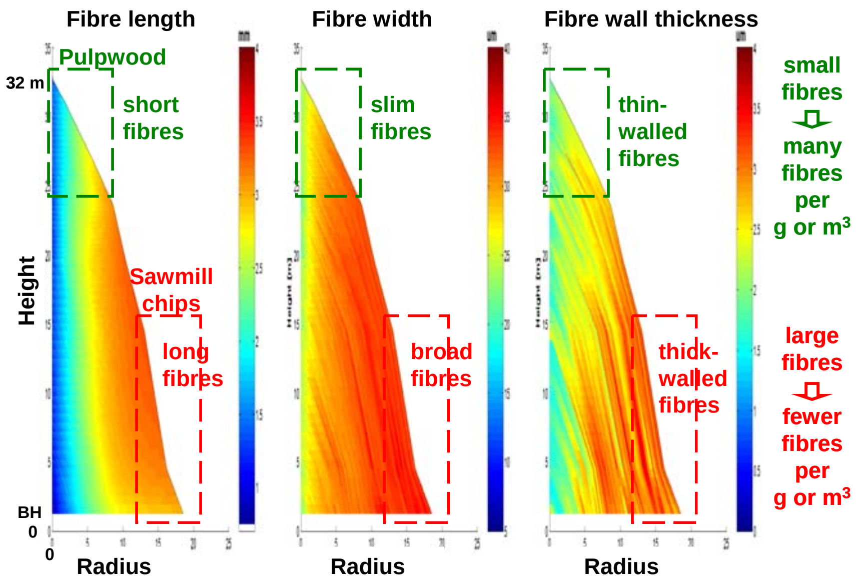

Figure 1: *Variations in fibre length, width and wall thickness within the stem of Norway spruce tree. The green rectangle close to the top indicates wood which will become pulpwood and the red rectangle close to the base indicates wood which will become sawmill chip.*

The effects of these differences in fibre properties are visualised in *figure 2*. Statistical distributions for the fibre dimensions have been estimated for fibres of pulpwood and sawmill chips. The formation of paper-like fibre networks from these fibres have been simulated, networks with the same grammage, g/m^3, and sheet density, kg/m^3. In the figure, the networks are visualised seen from the top, upper image, and in a cross-section, the thin lower image. The fibre network from pulpwood to the right is more uniform. The smaller fibres from pulpwood produce a sheet with a smoother surface which is also better for printing. The larger fibres of sawmill chips would, however, normally produce a stronger sheet (depending on what strength property has the highest priority for the product).

2.2 Typical allocation

In *figure 3*, a typical way to allocate wood to different types of products is illustrated. At the top of the figure, sketched trees of various sizes illustrate different ages when a forest is ready for different types of harvesting or silvicultural operations: pre-commercial thinning, first and second thinning, final cutting and possibly also harvesting of the stumps. Below this line, a typical segregation of the trees from a final cutting is shown and also how the different entities typically are directed to different products.

Here only five major types of products are shown, but the grey boxes behind them indicate that there are many other types of products and quality grades.

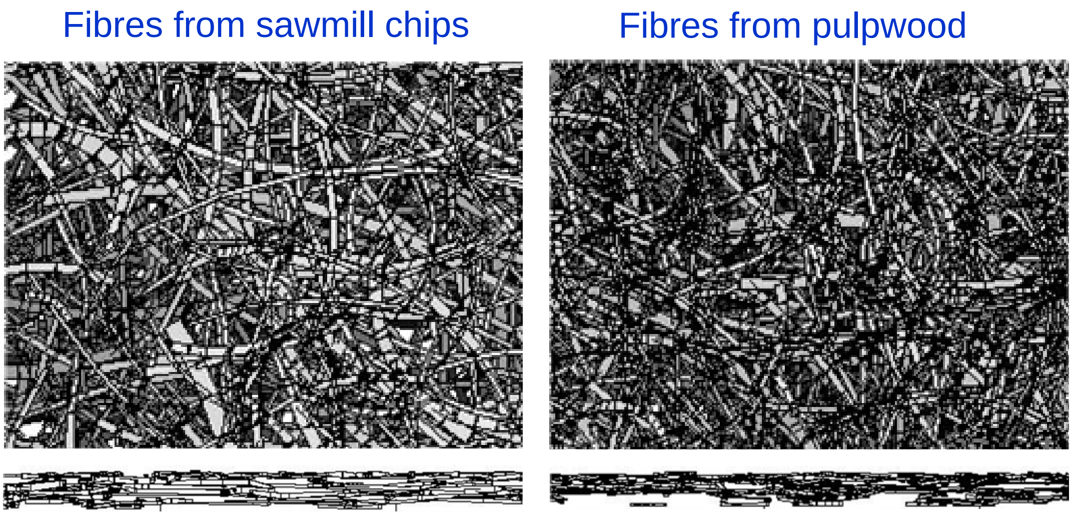

Figure 2: *Visualization of simulated paper-like fibre networks with fibres from sawmill chips, left, and from pulpwood, right. The upper images show the surfaces and the thin lower images cross-sections of the networks. Both networks have the same grammage, g/m2, and the same sheet density, kg/m*^{3}*.*

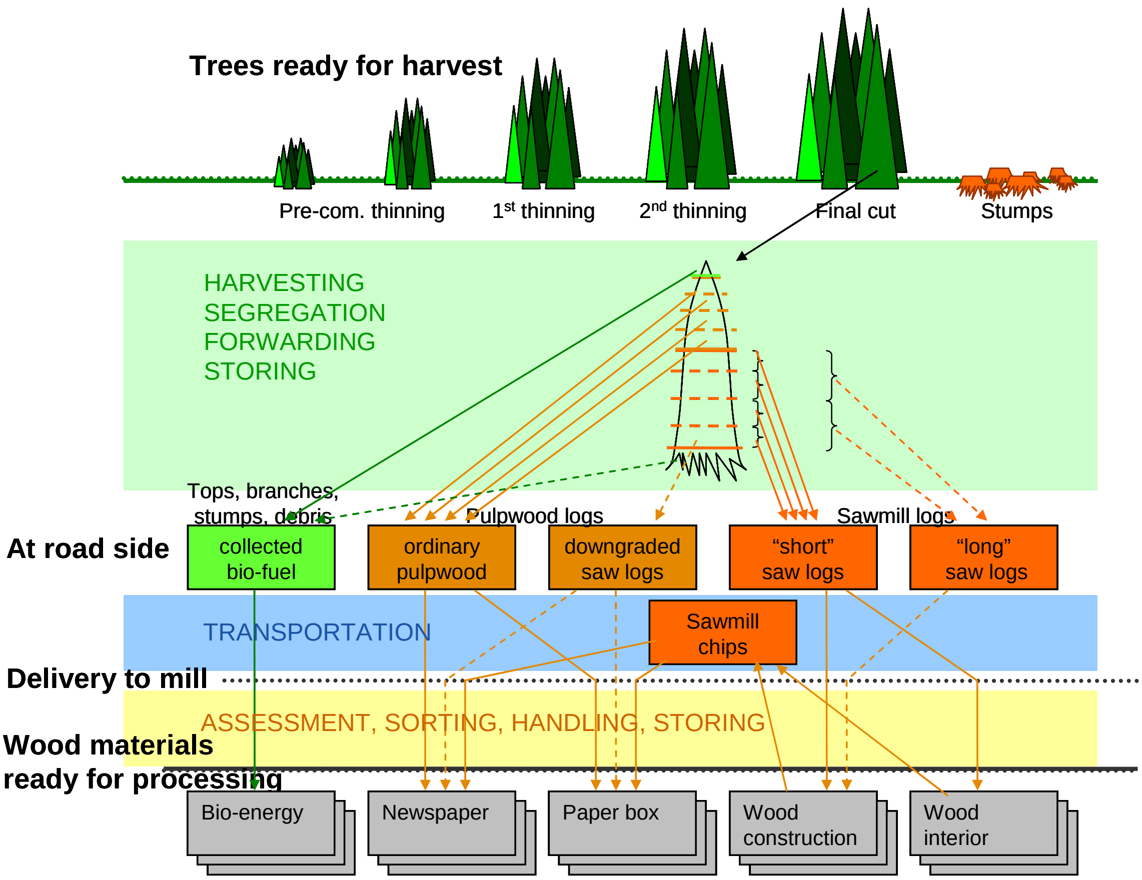

Figure 3: *Typical allocation of materials from final cutting of a softwood stand.*

3. Sustainability, properties and allocation

The allocation of suitable materials to mills, processes and products is obviously crucial for the sustainability of the forestry wood chains. All aspects of sustainability are influenced: environment, economics and society. If unsuitable material is allocated to a process, this will normally lead to losses of yield and value. The processing will normally be less efficient, with use of more material, energy, etc. than necessary per unit produced. The quality, product functionality and customer satisfaction may be lower. Or the material may have to be sent for processing at another process or mill, adding an unnecessary transportation into the production of the product.

In the EFORWOOD project, many of the issues related to the assessment of properties and allocation of materials are dealt within the workpackage 3.1 “Quality Assessment and Allocation” of Module 3 “Forest to Industry Interaction”. Important prerequisites for and activities involved in allocation, from the perspective of WP3.1, are summarised in *figure 4*.

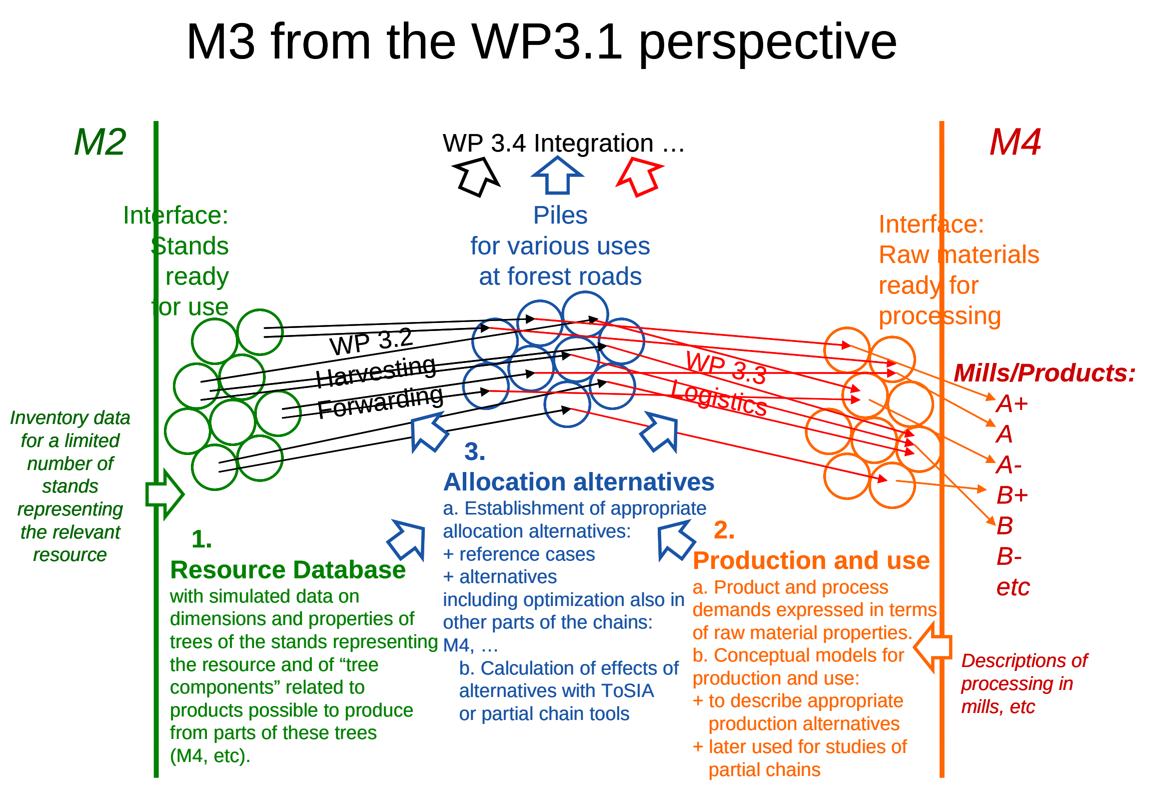

Figure 4: *Important prerequisites for and activities involved in allocation, according to WP3.1*

3.1 The available forest resource: volumes of wood with different properties

One prerequisite for good allocation is information about the available forest resource: How large volumes of wood with different properties are available for production of various products. In this report, a draft concept is presented for mapping of properties of forest resources and for classification of wood from a product perspective. The concept includes the building of “Regional Resource

Databases" with simulated data on available volumes, dimensions and properties of trees and of "tree components" related to products possible to produce from the trees harvested from the specific forest resources. Examples of "tree components" are pulpwood logs and sawlogs, sawmill chips and sawn goods, originating from thinning or final cutting of stands with different wood species of various ages and growth conditions. All data on stands, trees, logs, sawmill chips, wood and fibres are compiled in the database.

The concept of "Regional Resource Databases" has been used for some time at STFI-Packforsk. Models and tools have been developed in previous projects. Resource Databases have been built for supply areas of individual mills as well as for larger areas, now even for all Sweden. Very large sets of forest inventory data have been used. In the EFORWOOD project, the concept has been modified to become more generally and easily applicable. Similar predictions are now performed on data from a limited set of stands and trees, selected to represent the resource.

3.2 Production and use

After the building of the Regional Resource Database, a virtual representation of all components illustrated in figure 3 and data on their volumes and properties are available in the computer. Standard database tools may then be used to investigate the availability of wood meeting the different combinations of property demands of the specific product and process. Another prerequisite for good allocation is thus knowledge about products and processes and their demands on the raw materials, expressed in terms of properties of wood and fibres. This has, as far as is possible, been described in the EFORWOOD deliverable D3.1.2 "Key products of the forest-based industries and their demands on wood raw material properties".

Conceptual models are also needed for the production of the products and their use, in order to describe appropriate production alternatives. They will also be used later for studies of partial chains.

3.3 Allocation alternatives

When ToSIA, the Tool for Sustainability Impact Assessment and the main result of the EFORWOOD project, is ready for use, different policies and alternatives will be evaluated. Indicators linked to environmental, economical and societal effects will be calculated. ToSIA will, however, not check how realistic the simulated alternatives are. If an impossible alternative would be fed into the tool, such as using the worst, cheapest, locally available crap wood for production of the highest added value product, the calculations would probably supply indicator values telling that this is a splendid idea, a totally misleading answer. Therefore, it is crucial that realistic alternatives and scenarios are established for evaluation with ToSIA. And these alternatives would normally involve modifications in many processes along the value chains. Example: Improved procedures in silviculture, resulting in more favourable fibre properties, which makes it possible to produce lighter and thinner paper with the same functionality, thereby reducing use of the material, the need for transportation, etc.

Such realistic alternatives will often involve several parts of the production chains and can only be designed by experts in the field. A practical way to deal with this can be, as a first step, to establish appropriate reference cases including all the production chains. Data from the single chains and the case studies may be used as a backbone in the building of these references. The second step would then be to design alternatives, through the stepwise modification of flows, yields, energy consumptions, etc. along the chain. Then the effects of the alternatives are calculated with ToSIA or with partial chain tools, expressed as indicator values.

4. Regional Resource Databases

The concept of Regional Resource Databases was presented in a paper at the conference "Modelling the wood chain: Forestry – Wood industry – Wood product markets", organised by COST Action E44 on September 17-19, 2007, in Helsinki, Finland, The paper, see enclosure 1, shows an example of a very large scale versions of such databases, as well as of the limited scale version developed for EFORWOOD. For a general presentation of the concept and some examples, the reader is referred to the enclosure.

The scope of the concept may, however, be summarised as follows:

- The approach of Regional Resource Databases is designed to allow the investigation of consequences of different allocation alternatives with the same methodology in all countries and for different wood species.
- It is designed for general applicability
- The necessary preconditions are that:
  + inventory data are available or may be compiled for a limited number of stands and trees representing the forest resource and weight factors indicating how large part of the resource each of the stands represent.
  + models for growth, taper and properties are available from the literature of from previous work in the region or nearby regions
- The approach is, thus, possible to apply even if large sets of forest data are not available in region and is not dependent on the use of specific equipment and software in forest operations. Use of such software may, however, allow more detailed studies of the properties and on-line classification of logs. The potential of this will be illustrated in the project.
- The Regional Resource Database approach allows application of the method in many countries when the project is concluded.

The regional database is built stepwise through the use of an integrated set of models, estimation:

- size and shape of the stem
- growth pattern of the stem
- property distributions of the stem
- volumes, masses and properties for the technical "tree components".

5. Conclusions and continued work

5.1 Conclusions

The methods presented in enclosure 1 may be used to add information on properties of industrial importance to the data traditionally used to describe our forest resources. The methods also provide property information for technically important ”tree components”. These are parts of trees which may be considered for use in different mills and processes in the production of different products. This information is important for allocation of wood, in order to supply different industries with more uniform and suitable raw materials for specific products, with the limits set by availability, logistics, economics, etc.

The starting points are inventory data for the forest resource of interest and a set of integrated models for the wood species and properties to be included. In the EFORWOOD version of the concept, large-scale datasets of inventory data are replaced with data on a limited number of stands and trees, selected to represent the resource. Examples are given.

5.2 Continued work

Properties relevant for both solid wood, fibre and bio-energy chains are already included in the Regional Resource Database, but in the current draft and test phase wood density and fibre dimensions have been emphasised. Now, further properties will be worked upon and visualised and inventory data for more regions will be compiled. A new report, further addressing the case study level, is scheduled for month 31 = May 2008.

6. References

See the article in Enclosure 1.

Modelling and simulation of properties of forest resources and along the paper value chain

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ABSTRACT

Wood shows a large variation in properties; between wood species and clones, growth conditions and parts of trees. This means that it is possible, but not always economically feasible, to find wood matching a broad spectrum of property specifications for different products and processes. But it is also a weakness of wood as a material. Unwanted property variations lead to reduced yield, increased costs and problems with product quality in the industry. Therefore, improved procedures are needed to predict properties of stands, trees, logs and chips and to allocate the wood optimally to different mills and products. The paper illustrates how this can be supported by using models and simulations. Forest data on stands and trees have been used as input data to models to estimate important wood and fibre properties and variations within and between stands and trees. The properties have also been estimated for parts of trees of technical interest; for pulpwood logs and the parts of sawlogs which will become sawn products and sawmill chips. Inventory data have been used to simulate large numbers of stands and trees for representative descriptions of regional forest resources. Regional Resource Databases have been compiled, in which estimated properties of logs and chips has been added to the traditional inventory data. Such databases have been used to investigate what properties and volumes of wood for different uses can be obtained from the forest available in the region and what benefits can be reached with a more selective use of wood. Effects from use of different sources of fibres (pulpwood and sawmill chips of different origins) on paper-like fibre networks have also been simulated. Properties of importance for pulp and paper have been emphasised, but the concept is also tested for properties of solid wood and knots. The concept is now used in projects for the industry.

INTRODUCTION

A wide spectrum of products of major importance for the society is manufactured from wood. Products from wood have become part of the culture in many countries around the world. But wood is also a renewable raw material for the production of modern materials with new functionalities, which opens up for new sound solutions from a sustainability perspective.

As a material, wood shows a large variety in properties, between wood species and clones grown in different regions, forest stands of various growth conditions, individual trees in stands and parts of trees. This variety means that it in principle is possible to find wood with properties matching a broad spectrum of specifications for different products and processes, if economically feasible. But it is also a weakness of wood as a material. Unwanted property variations lead to losses in yield, production efficiency and difficulties with product quality. Therefore, the industry prefers raw materials with uniform and predictable properties. This is not possible to fully achieve when wood is used. But part of the property variations is possible to predict. A current challenge of forestry and the forest based industries is to develop better procedures to predict properties of stands, trees, logs and chips and to allocate the harvested wood optimally to different mills and products. Optimal allocation will mean that some variations have to be accepted to keep costs, transportation, etc at reasonable levels. Therefore, it is also important to provide the mill with information about the properties of the wood supplied, to support efficient operation and product quality.

In the paper, some tools based on modelling and simulation developed to support this are illustrated. One example shows the use of large sets of forest inventory data to simulate properties of specific forest resources, such as the resources in a region or a supply area of a mill. Properties of harvested materials, sawlogs and pulpwood logs from thinning and final cutting operations, are also estimated for stands in the region of various ages and growth conditions. This is done also for the parts of the sawlogs which will become sawn goods and sawmill chips. All data on stands, trees, logs wood and fibres are compiled in databases useful in both research and applications. Another example illustrates similar predictions based on data from a limited set of stands and trees, selected to represent the resource. And a third example illustrates simulation along the value chain, to support the optimal use of the materials possible to obtain from the resource. The examples are mostly relate to wood, fibres, pulp and paper, but the concept may be used also on properties of knots and products from solid wood.

EXPERIMENTAL METHODS

The approach

The approach developed is performed in two steps:

1. Careful selection of stands, trees and samples reflecting effects of the most important sources of property variations in the region. Detailed analyses of the samples for the most important wood and fibre properties. Compilation of data on properties of stands, trees, wood and fibres in a database. Modelling of the properties and their variation.
2. Use of “low-cost data”, such as forest inventory or harvester data, and the models to simulate large numbers of stands and trees, to get a representative description of the regional forest resource and its variability. Simulation of volumes and properties of parts of these trees of technical interest (logs, chips). Compilation of a Regional Resource Database useful to study the resource and the effects of different allocation alternatives.

Sampling and measurements

Well designed strategies for the selection of suitable stands and trees to be sampled and for the sampling itself are crucial. The strategies developed have now been applied on several wood species and in many parts of the world. Access to efficient measurement instruments for important properties is also fundamentally important for the application of this approach. For this purpose, a Wood and Fibre Measurement Centre with unique and powerful equipment has been built. One of these is the SilviScan instrument for high resolution measurement on wood samples of radial variations of many wood and fibre properties, such as wood density, fibre width (radially and tangentially), fibre wall thickness, microfibril angle and wood stiffness (estimated acoustic MOE) (Evans 1994, 1999). Examples from measurements are shown in Fig. 1.

Other examples are procedures and equipment to determine the lengths and widths of fibres and vessel elements, and their relative numbers, in pulps or their radial variations in wood (Granlöf *et al* 2006). Traditional methods for evaluation of pulp and paper properties are also used, see Fig. 2, showing differences in sheet density and air permeance between laboratory sheets produced from different types of logs and chips of Scots pine (Lundqvist *et al* 2007a, b). That project included both the solid wood and the fibre based industries (Usenius 2007) and forestry factors.

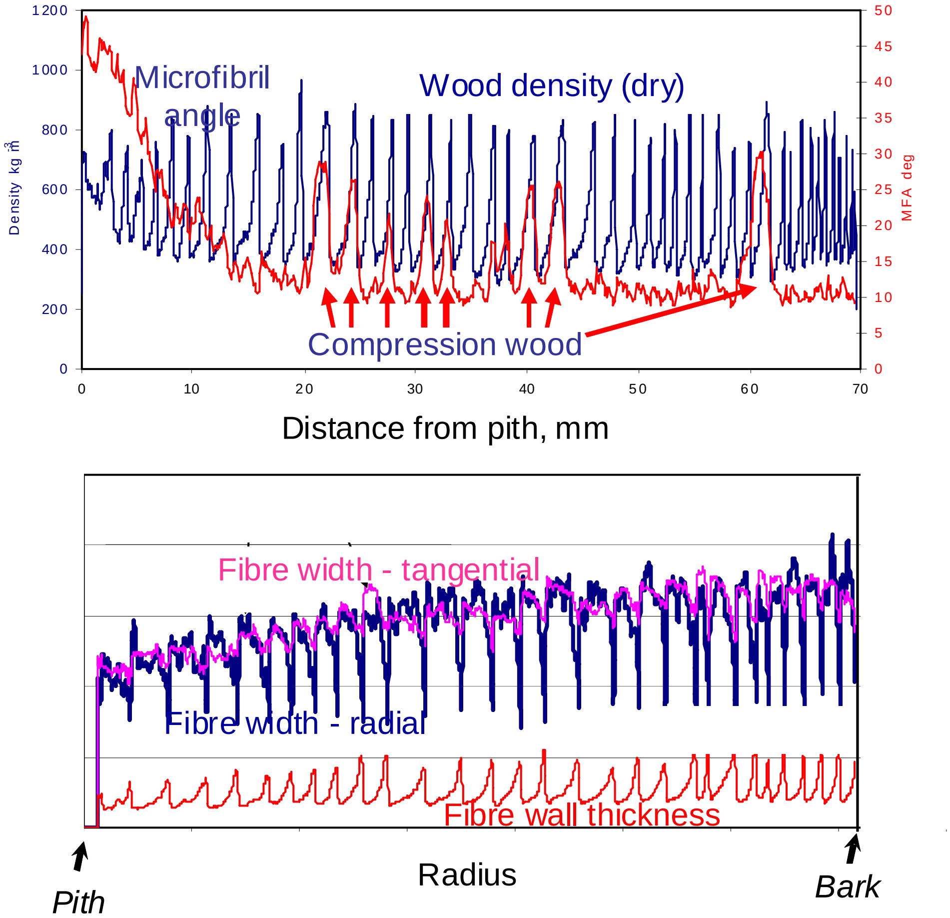

***Figure 1:** Property variations from pith to bark as measured with SilviScan on a sample of Norway spruce with 29 annual rings. Upper graph: Wood density (measured on dry sample, about 25 %higher than the basic density, microfibril angle and presence of compression wood indicated. Lower graph: Fibre width and fibre wall thickness. (Evans 1994, 1999)*

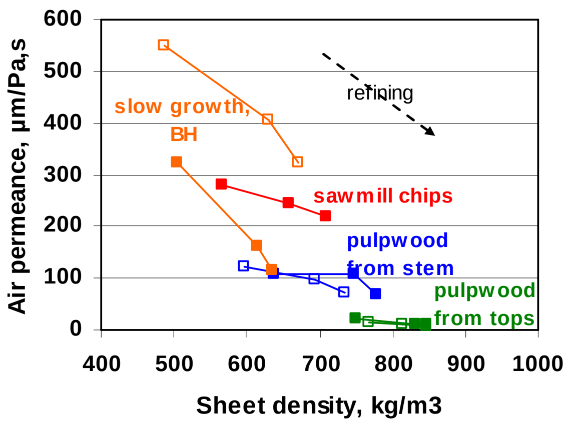

***Figure 2:** Density and air permeance (porosity; Gurley, extended measurement range) of laboratory sheets produced from pulps of various origins and refining (PFI mill). The pulps are produced with laboratory kraft cooking from wood representing different parts of Scots pine trees. The sheets from fibres of top logs have a high density and low porosity even if the pulps are not refined. The sheets from the most slow-grown wood have a high porosity and low density even if produced from refined pulp. (Lundqvist et al, 2007a, b)*

Models and simulations

Sets of integrated models are used, including models for taper of trees, fibre dimensions and wood density. Most of the models have been developed within projects in various constellations of cooperation. Depending on the purpose of the simulation and application considered, models with different levels of detail, such as averages for stem cross-sections, annual rings or parts of rings, and with different sets of independent variables are used. Below, a set of models used for simulation of cross-sectional averages at arbitrary heights of Scots pine is shown: Eq. 1 for wood density (Wilhelmsson *et al* 2001) and Eq. 2-4 for fibre length, fibre width and fibre wall thickness (Lundqvist *et al* 2005). The models are based on data from Swedish conditions.

$$WD_h = 364.4 - 17.58 * AGW_h - 0.607 * (\ln N_{bh})^3 + 0.417 * (\ln N_{bh})^3 * e^{(\frac{d_h}{d_{bh}})^7} \quad (1)$$

$$FL_h = -0.56 + 0.69 * \ln(N_h) + 0.33 * \ln(AGW_h) - 0.65 * e^{(\frac{-h_{rel}}{0.13})} + 0.00043 * tsum \quad (2)$$

$$FW_h = 23.99 + 3.18 * \ln(\frac{d_h}{2}) - 5.25 * e^{(\frac{-AGW_h}{1.87})} \quad (3)$$

$$FWT_h = 1.16 + 0.24 * \ln(\frac{d_h}{2}) - 0.23 * \ln(h_{rel}) + 0.00030 * tsum \quad (4)$$

Where: WD_h = average wood density of cross-section at height h
FL_h = average fibre length of cross-section at height h
FW_h = average fibre width of cross-section at height h
FWT_h = average fibre wall thickness of cross-section at height h
d_h = diameter under bark at height h; d_{bh} = diameter at breast height 1.3 m
N_h = number of growth rings at height h; N_{bh} = number at breast height 1.3 m
AGW_h = average growth ring width in cross-section at height h
h_{rel} = relative height in tree ($0< h_{rel}<1$)

The simulation of internal property variations within a tree starts with simulation of its external size and internal growth structure, to the left in Fig. 3. The resulting data on locations of annual rings, etc., are then used to simulate the properties at different heights in the tree. In Fig.3, a model including the radial variation has been used, mid part of the figure (Olsson *et al*). The full picture is obtained by combining these pieces of information, to the right.

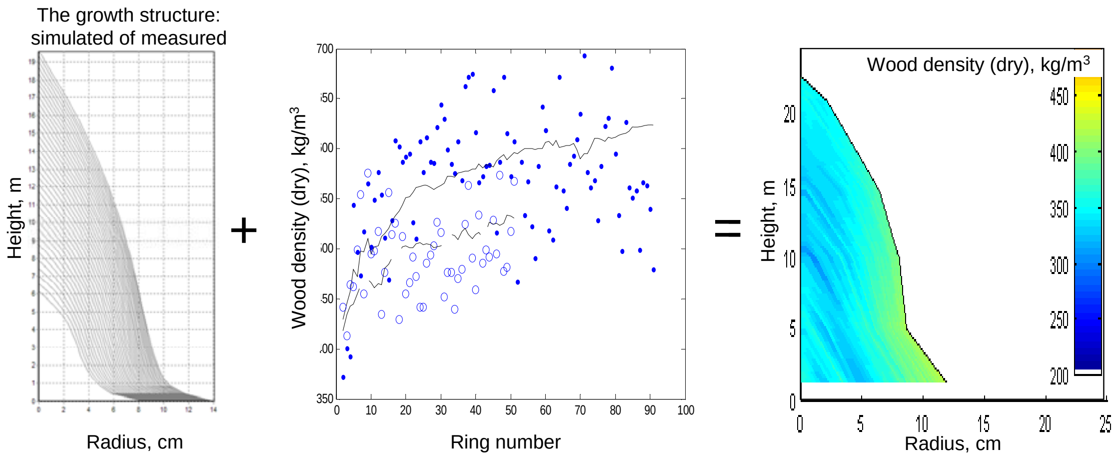

Figure 3: The growth structure and radial variations are used to build a map of the variation in the whole stem.

From the basic fibre dimensions: fibre length, width and wall thickness, several more product-oriented properties may be calculated, such as fibre coarseness and fibre collapsibility. Properties relevant for pulp and paper have been emphasized, but properties of knots have also been simulated, using models from the literature.

Fig. 4 illustrates how properties of logs and ships are estimated. After the simulation of size, growth pattern and internal properties of the stem, to the left, the stem is divided in logs and the sawlogs are further divided into the parts which will become sawn goods and sawmill chips. This corresponds to the bucking or cross-cutting operations. Then the properties of each component are calculated. The simulations and calculations can be done with different level of detail depending on application. For pulp and paper, statistical distributions of various fibre dimensions are important. An estimated combined distribution for fibre length and wall thickness for one log is shown to the right in fig. 5. Measured and simulated data on stands, trees, wood and fibres are compiled in a Regional Resource Database.

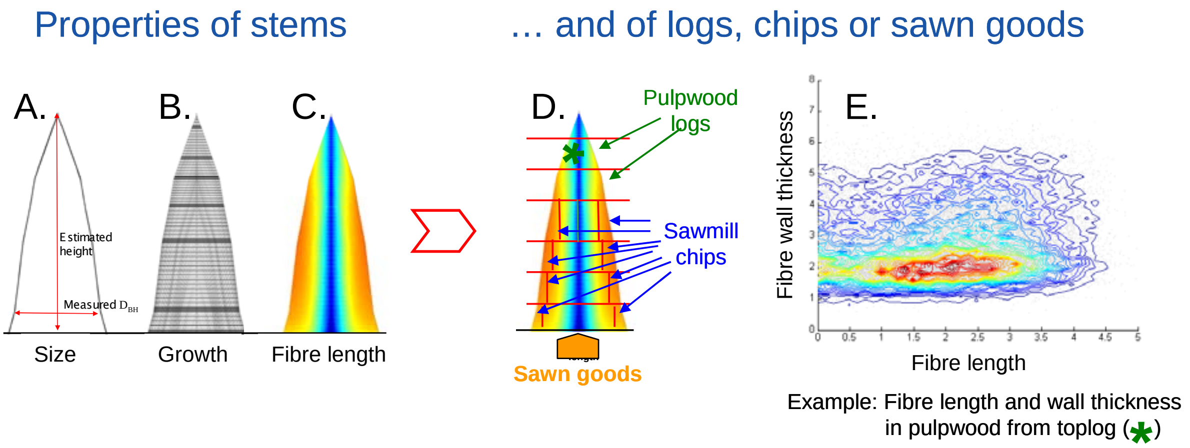

Figure 4: The simulated stems are divided into pulpwood logs and sawlogs, which are further divided into the parts which will become sawn products and chips. The properties of all components are calculated. This combined distribution for fibre length and wall thickness of a log (E) represents the highest level of detail applied in the simulations.

RESULTS AND DISCUSSION

With the database in place, standard database software and dedicated tools developed for the purpose are used to study the resource and to investigate effects of different alternatives to utilise wood from various parts of different types of stands and trees. Three examples are shown below.

Large-scale databases on forest resources

The first application of the concept developed was the simulation of the wood and fibre properties of the forest resource available in the supply area of a pulp and paper mill. Inventory data from stands in the area owned by the paper company were used to represent the forest. A Resource Database was built, including also some pulp and paper-oriented fibre properties of special interest for the products of this mill. The database was then used to investigate how the variations in wood and fibre properties at the mill could be reduced.

While this work was done, southern Sweden was hit by a severe storm. In some hours, a wood volume similar to the annual harvest in all Sweden was on the ground. Many questions were raised about how to use of this wood. Mills in other parts of Sweden asked how their products would be affected if they used storm-felled wood from the south. This inspired us to develop a National Resource Database with estimated properties for the forest of all Sweden. With this database, we are now able to support industry and forestry with more rapid answer to such questions. It is also useful in research and in the development of other applications.

Data describing the national forest resource were obtained from the Swedish National Forest Inventory Database (Riksskogstaxeringen), managed by SLU. SLU has compiled a large dataset, based on the inventories performed during 2001-2005. It includes information on about 23.000 inventory plots and 380.000 trees distributed over all the Swedish forest resource. It also includes estimates of trees heights and ages, based on models developed at SLU. These data were used as input data to simulate the size, taper, internal growth pattern and a number of wood and fibre properties for all Norway spruce and Scots pine trees, as described above. At this stage, wood density and fibre properties have been emphasised, but information on knots and other properties may be added. All stems have been divided into logs, totally more than one million logs, and the sawlogs into what will become sawn goods and chips. The dataset also includes information on the status of all stands: ready to thin, not ready or ready for final cutting, etc.

Standard database software and dedicated evaluation tools are then used to select specific data from the database, make further calculations, etc. Important properties of logs considered for a specific product can be studied and influences of various factors investigated, such as growth rate or region of origin. In Fig. 5 an example is given related to sawn products. Data on the wood density of the inner part of the sawlogs, which will become sawn goods, from pine trees in a specific region have been selected from the database, together with the diameters and average growth ring widths of all the selected logs. The figure illustrates the density distribution for the logs available for a sawmill and how the density typically increases with log diameter and decreases with average growth ring width. A good thing with this approach is that the data of the resource database are based on the real trees of the region, thus reflecting the typical local growth conditions, age structure, etc, of the region.

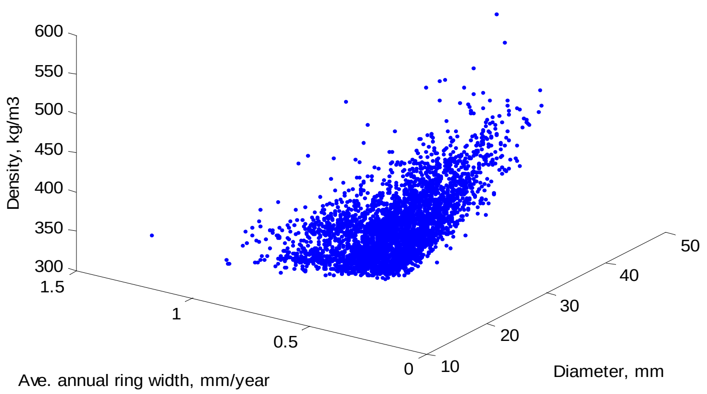

Figure 5: The basic density of the inner part of the sawlogs of pine from a region in Sweden, simulated from inventory data. The figure illustrates the density distribution for the logs available and how the density typically increases with log diameter and decreases with average growth ring width.

Limited scale Regional Forest Resource Databases

In many cases, it is not possible or reasonable to build very large databases. Large-scale inventory data may not be available. Only a limited size resource is relevant for the specific mill. All property models needed may not yet be fully developed or they may need a first check-up or modification to match important local conditions. Or the scope may be to in a pre-study get a better feeling for the property variations, before entering larger-scale applications.

A special version for such purposes will be applied in the project EFORWOOD. The project objective is to develop a tool for assessment of total sustainability effects of policies and actions in the whole forestry wood chain. The allocation of wood to different products and processes has obvious sustainability effects regarding transportation, product yield, energy and chemical consumption, product quality (Lundqvist 2007b), etc. Small Regional Resource Databases are being built to through light on these effects. The special version will make it possible to do this also in regions and for wood species, where large-scale data are not available. The procedure designed is to use limited set of stands (plots) and trees selected to represent the regional resource, rather than large set of inventory plots laid our based on geographic coordinates or ownership. The number of stand needed will depend on the heterogeneity of the resource.

A limited number of variables influencing the most important properties are selected, for instance age of the tree. Based on the local variation of these variables, a limited number of classes are defined for these variables, for instance age classes representing the variations in the resource. Example: In an EFORWOOD case study on Scots pine in the county of Västerbotten in northern Sweden, stand/tree age, altitude and site index were identified as the most influential variables. Regional statistics showed that, for this region, the resource and also the wood from thinning and final cutting could be reasonably well represented with 4 age classes, centred round the ages 50, 75, 100 and 125 years, see Fig. 6. Analogously, 2 altitude classes (close to 200 m and 350 m) and two site index classes (close to P16 and P18 (the estimated height for large trees in a 100 years old pine stand)) were defined. In this way, 4 x 2 x 2 = 16 types of stands were defined to represent the pine resource of the region.

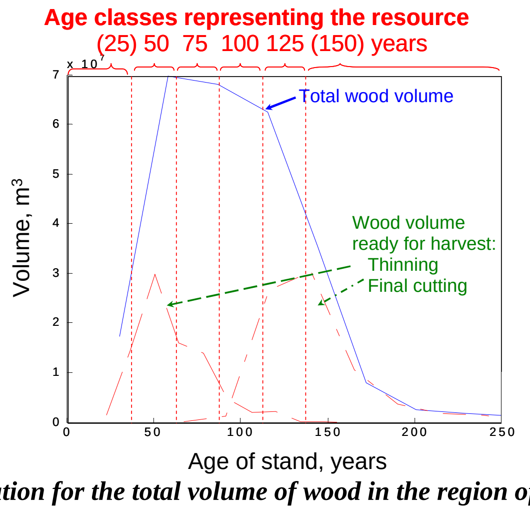

Figure 6: Age distribution for the total volume of wood in the region of Västerbotten in the north of Sweden, as well as for wood ready to harvest in thinning and final cutting. Age classes centred around 50, 75, 100 and 125 years of age were defined to represent the resource and the wood obtained from different harvesting operations.

To start with, one stand of each class was selected, together with a number of trees per stand. Data on these stands and trees were compiled for the simulation of a small scale Regional Resource Database. (16 stands only are used in this example, but number of selected stands can in this case easily be increased a lot.) Fig. 7 illustrates the sizes of these trees of various ages and growth conditions: breast height diameter (callipered) and tree height (estimated by SLU).

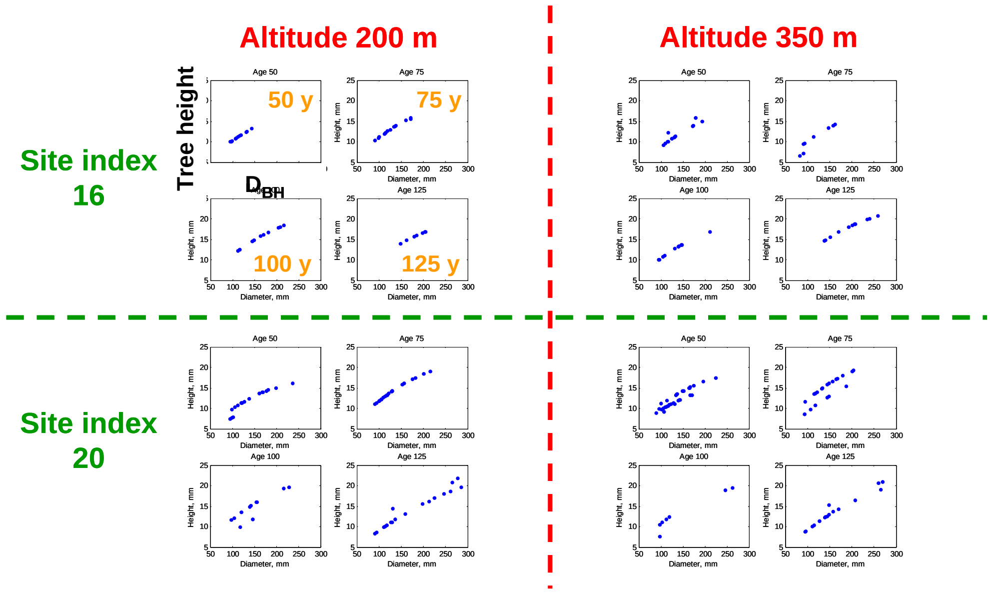

Figure 7: Breast height diameter (callipered) and tree height (estimated by SLU) of the trees from the 16 stands selected to represent the pine resource of Västerbotten in the north of Sweden.

The properties of the trees are simulated and the stems are divided into parts, as described above. Averages are calculated for each part. This is illustrated in Fig.8 with simulated data for fibre length from one tree. The tree is close to 20 m high and produces 3 sawlogs and 2 pulpwood logs. The average fibre length of the pulpwood log at the top of the tree is estimated to about 1,8 mm only. The fibre length of the chips from the sawlogs is estimated to about 3,1 mm. The data may also be presented from a mill perspective as a function of log diameter, shown to the right, or in more elaborated ways similar to Fig. 6, but then data on more stands would be preferred.

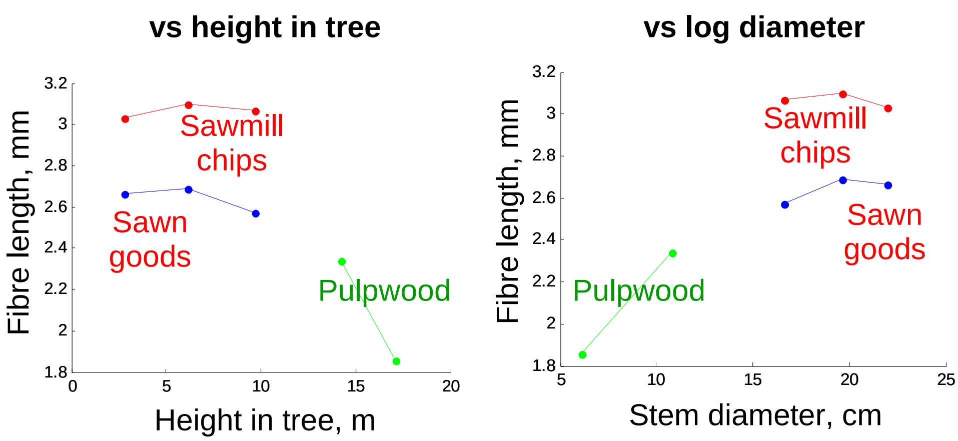

Figure 8: Average fibre lengths of pulpwood logs and what will become sawn goods and sawmill from one of the trees in Fig. 7, as a function of the position along the stem, left, and the diameter of the log, right.

Properties along the paper value chain

In many cases, the properties preferred by the industry are known and estimated values may even be included in the database. Then, the database may be used as it is to get a better feeling for how the wood and fibres from the regional resource could be used, considering properties and volumes preferred by the industry and available in the forest, logistics, costs and other factors. In other cases, more complex analyses have to be done to predict how the wood and its fibres will influence the properties of a specific product. This is often the case for pulp and paper, where not only the basic fibre dimensions themselves but also relationships between them are very relevant, and often the statistical distributions more relevant than the averages. For this purpose, more detailed models on fibre properties in trees have been and more complex models on properties of fibre-based products have been developed. Fig. 9 illustrates the within tree variation of the basic fibre dimensions in a spruce tree, estimated with such models. We have also developed tools to predict how these fibre properties may influence properties of the products. This is illustrated with two simulated paper-like fibre networks in Fig. 10 (Thomsson *et al* 2006).

The green rectangles close to the top in Fig. 9 indicate what will typically become pulpwood. The fibres in this part of the tree typically are short, slim and thin-walled compared to those in sawmill chips from the part indicated with red rectangles, even if the distributions overlap. This means that the fibres from pulpwood typically are smaller and will supply more fibres per gram.

The effects of these differences in fibre properties are visualised in Fig. 10. Statistical distributions for the basic fibre dimensions, see also Fig. 6, have been estimated for fibres of pulpwood and sawmill chips. The formation of paper-like fibre networks with the same grammage, g/m^3, and sheet density, kg/m^3, have been simulated from these fibres. The networks are visualised seen from the top, upper image, and in a cross-section, the thin lower image. It may be seen that fibre network from pulpwood to the right is more uniform. The smaller fibres from pulpwood produce a sheet with a smoother surface which is also better for printing. The larger fibres of sawmill chips would, however, normally produce a stronger sheet (depending on what strength property has the highest priority for the product).

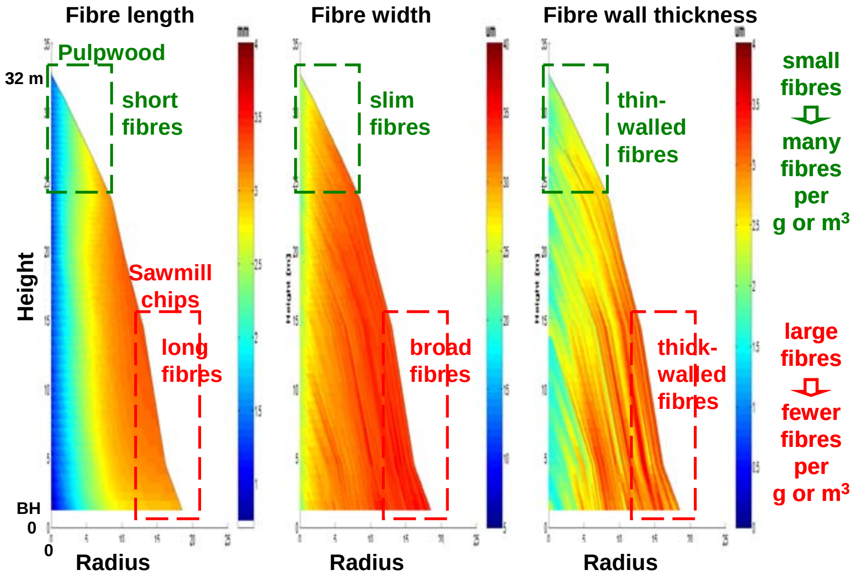

Figure 9: Variations in fibre length, width and wall thickness within the stem of Norway spruce tree. The green rectangle close to the top indicates wood which will become pulpwood and the red rectangle close to the base indicates wood which will become sawmill chip.

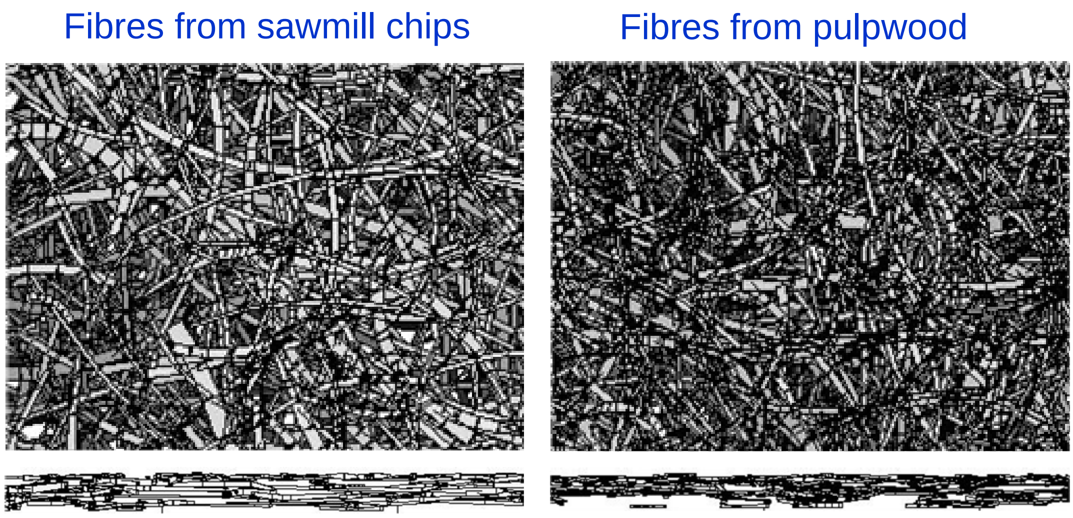

Figure 10: Visualization of simulated paper-like fibre networks with fibres from sawmill chips, left, and from pulpwood, right. The upper images show the surfaces and the thin lower images cross-sections of the networks. Both networks have the same grammage, g/m2, and the same sheet density, kg/m3. (Thomsson et al 2006)

With the tools developed, it is also possible to investigate the internal structures of the networks, to compare number of bonds, lengths of free fibre segments, void volume between the fibres, etc., which influences the paper.

CONCLUSIONS

The methods and results presented above offers a number of examples of how models and simulations may be used to add information on properties of industrial importance to the data traditionally used to describe our forest resources, and also to describe how these properties influences the properties of products of the industry. The approaches developed are now used in several projects. Properties of resources are investigated in several countries in cooperation with different partners. Further wood species are investigated with measurements of property variations and modelling. The development of efficient methods and tools used in these projects has demanded very large efforts during many years, but with the tools now at hand, the experiences of using modelling and simulation to improve the overall efficiency in the wood chain are very positive. Another experience made is that it is always very important to build teams of partners with good knowledge on the conditions specific for the region and for the products addressed. Expertise along all part of the wood chain to be covered is very important.

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