FlexWood
Flexible Wood Supply Chain

Final Report

FlexWood Project

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SEVENTH FRAMEWOR PROGRAMME

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1. Executive summary

The EU-funded Collaborative Project FlexWood – Flexible Wood Supply Chain (Grant agreement no.: 245136), is an FP7 project with a three year duration that began November 1st, 2009 and was completed October 31st, 2012. The project Consortium consists of 14 partners representing 9 countries and is comprised of leading SMEs, universities and research centres and associations who contributed complementary experience and expertise.

The overall objective is a novel logistic system, 'FlexWood', which provides value recovery along the wood supply chain. This online platform integrates

- advanced quality and quantity information on wood resources measured in the forest with novel technology

- optimisation models for tactical and operational planning (bucking, harvesting, allocation of wood)

- optimisation models and enhanced processes for novel and more flexible concepts for mill production and

- improved information transfer between all stages of the wood supply chain to create new knowledge for decision making.

Within the FlexWood concept, existing solutions for value recovery opportunities in these areas were tested and/or adapted or developed, which was followed by an interlinking of the single solutions that allows the modelling of the entire information flow with benefits and efficiency gains in time, quality and cost.

Reports are available on the results of the different Work Packages (WP); these cover the following areas of the wood-supply-chain:

* demands of main industrial sectors in *"WP 3000 Meeting of Industrial Requirements"*;

* forest resource inventory in *"WP 4000 Integrated Forest Inventory Design for Optimised Quality and Quantity Assessment of Wood Resources"*;

* harvest and transport in "*WP 5000 Novel Harvesting and Logistic Concepts for Integration of Forestry with Industry"*;

* efficient mill production based on advanced information in *"WP 6000 Flexible and Customer Adapted Mill Production"*;

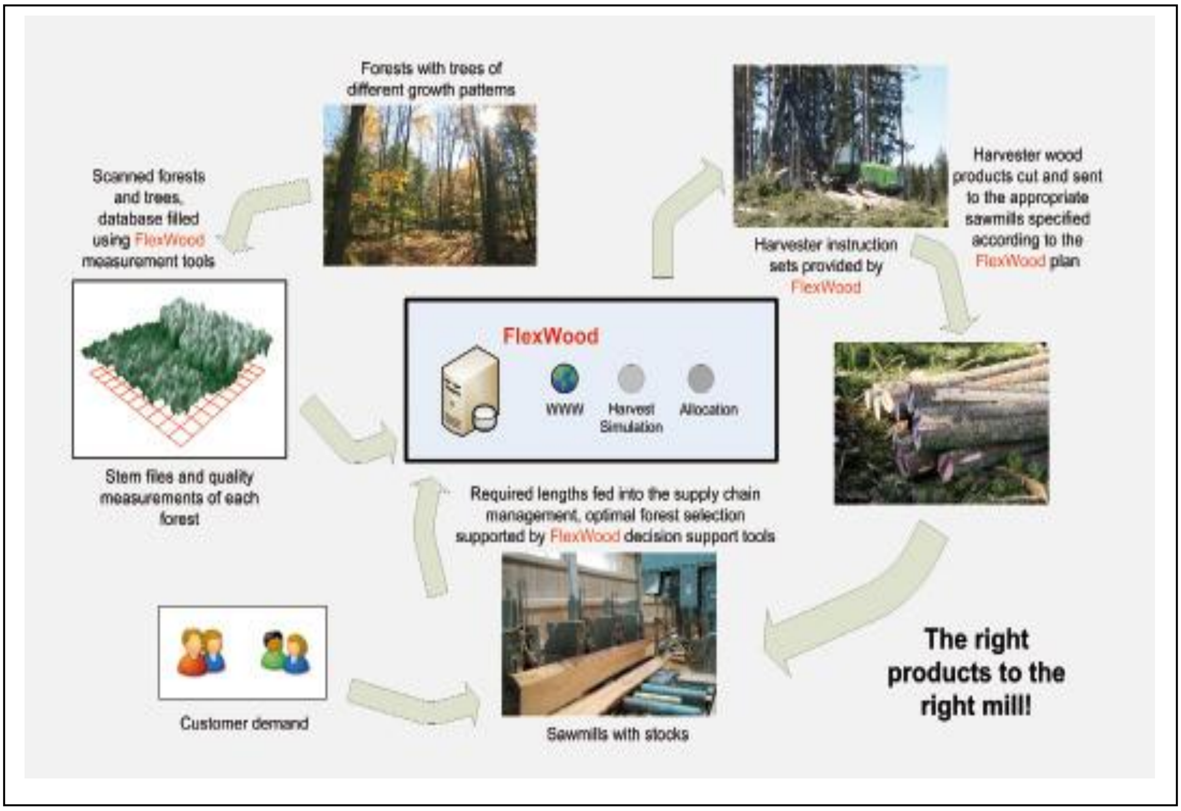
* combining the previous WPs in a novel logistic system using IT components "*WP 7000 Communication Infrastructure for the Support of Increased Wood Supply Efficiency"*; and

* demonstration of the concept on Use Cases in Germany, France, Sweden and Poland in "*WP 8000 Implementation and Demonstration of the FlexWood Concept"*.

2. Project Context and Main Objectives

The overall objective of the FlexWood project was to develop and to build a novel logistic system, incorporating better information on wood resources and enhanced optimisation models, to respond more efficiently and adequately to the demands of industrial sectors. In other words, the aim was to reach a better matching between supply and demand and to provide a wood supply chain (WSC) driven by demand, where requirements of industries pull the activity of the rest of supply chain, until the forest exploitation (and not the opposite, as still often observed today). Finally, this increased flexibility and the better knowledge of resources would create value throughout the WSC.

In addition, the growing needs (including through the development of wood energy) and the requirements of sustainable development in Europe make efficient use of the resource even more important.



FlexWood - towards a demand-driven WSC

The novel logistic system, 'FlexWood', provides value recovery along the wood supply chain by integrating the following points in the online platform:

- advanced quality and quantity information on wood resources measured in the forest with novel technology

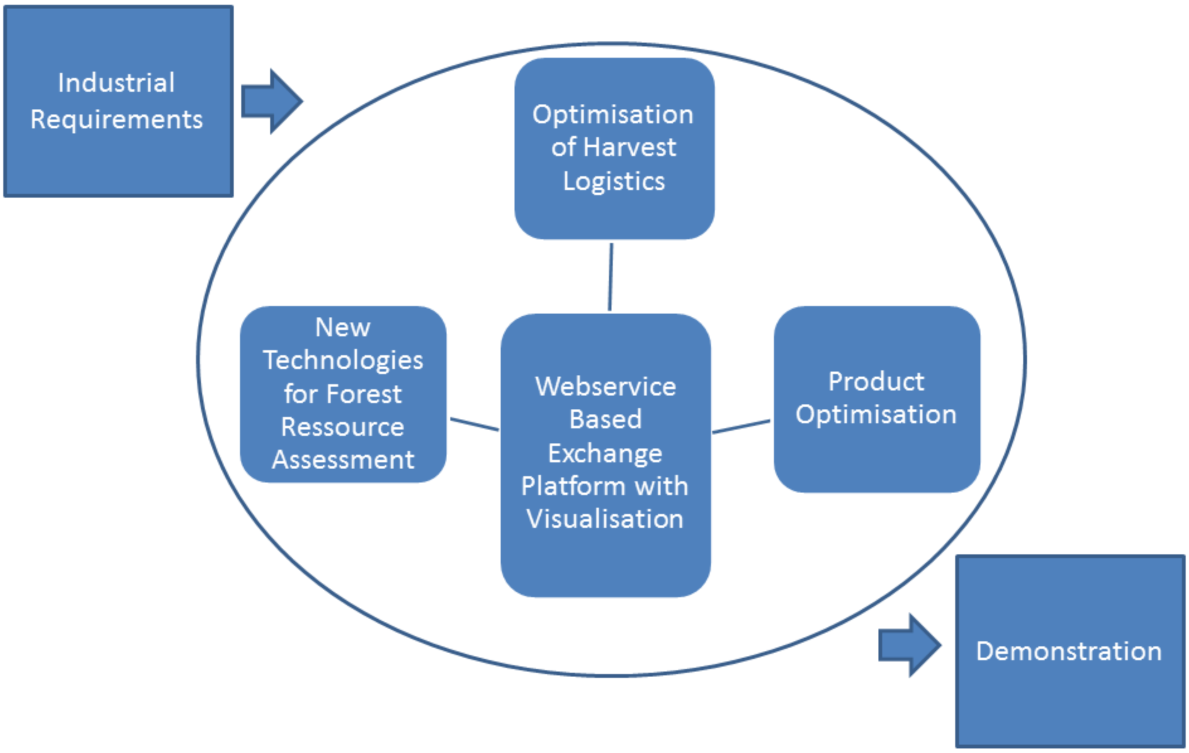
- optimisation models for tactical and operational planning (bucking, harvesting, allocation of wood)

- optimisation models and enhanced processes for novel and more flexible concepts for mill production and

- improved information transfer between all stages of the wood supply chain to create new knowledge for decision making.

Within the FlexWood concept, existing solutions for value recovery opportunities in these areas were tested and/or adapted or developed, which was followed by an interlinking of the single solutions that allows the modelling of the entire information flow with benefits and efficiency gains in time, quality and cost.

The research carried out within the project can be visualised as such:



The strategy was to combine the three research areas of **new technologies for forest resource assessment** (inventory), **optimisation of harvest and logistics** and **product optimisation** (saw mill) in a novel logistic system that makes use of IT components; the **webservice based exchange platform.** Basis for the research was first provided by the **industrial requirements** and the results were finally tested and evaluated in four Use Case **demonstration**.

<u>Industrial requirements</u>

The main objective of this work package (*WP 3000 Meeting Industrial Requirements*) was to express and to describe the demands of main industrial sectors within the Wood Supply Chain (WSC) in terms of wood raw material qualities. It covers production of solid wood products (sawmills), pulp and paper (fibre) and bio-energies. It is often observed that industrials of the WSC must produce on any wood materials available and delivered, where wood raw material pushes the manufacturing of certain products. Combining industrial demand with new technologies such as remote sensing, which enable to identify wood properties early in the chain, opens the door for more efficient processes and material uses.

New technologies for forest resource assessment

In this work package (*WP 4000 Integrated Forest Inventory Design for Optimised Quality and Quantity Assessment of Wood Resources*) the aim was to develop an integrated forest inventory design for optimized quality and quantity assessment of wood resources. The main objective was to use remote sensing data from both aerial (ALS) and terrestrial (TLS) laser and optical technologies (multispectral and hyperspectral images) to obtain advanced quality and quantity information on wood resources measured in the forest with the novel technology. The specific research objectives were

- to develop and optimise ALS and TLS methods for assessment of wood quality and quantities at high spatial resolution and validate these methods, and
- to optimise the combination of different data sources, such as ALS, TLS, existing geo-spatial data, optical sensor data and field measurements, in description of tree and wood properties.

Optimisation of harvest and logistics

The first thing done in this work package (*WP 5000 Novel Harvesting and Logistic Concepts for Integration of Forestry with Industry*) was to develop a generic method to describe and measure different wood supply systems. According to that the special circumstances for small private forest owner's situation in central Europe were described. Thereafter, the data needed to build a planning model was described; especially supply descriptions of forest stands via laser scanning and industrial demand. In addition, more flexible means to adapt the bucking processes in the cut to length harvesters were investigated. Finally, the work package ended with the development of a planning model to match industrial demand with forest supply efficiently using operational means i.e. harvest- and transport equipment and road network.

Product optimisation

There were three main objectives of this work package (*WP 6000 Flexible and Customer Adapted Mill Production*); (1) To collect data (e.g. scanning technology) to provide information for modelling the manufacturing processes (saw mill and secondary conversion) and further on to final products (sawn timber and value added components); (2) To create concepts for converting wood raw material into sawn timber and wooden components through radically more flexible manufacturing processes than in the current situation. (3) To integrate the forest optimisation models from WP 5000 into conversion models.

Webservice based exchange platform

The role of this work package (*WP 7000 Communication Infrastructure for the Support of Increased Wood Supply Efficiency*) in FlexWood was to deliver and implement an architecture to provide the IT infrastructure for collaboration of many forest related services. This collaboration is a key to the success of the FlexWood project as it allows a complete integrated model of the forest supply chain to be achieved. Only by bringing the various services together can there be a synergistic effect, to realise many new types of knowledge which can be determined before, during and after harvesting. The other important aspect of the architecture is the multitude of potential stakeholders in different locations capable of using the system. The architecture must therefore support multiple views of the operations and data from a wide variety of devices and only allow certain functions and results to be available to each stakeholder.

Demonstration

There were two tasks in this work package (*WP 8000 Implementation and Demonstration of the FlexWood Concept*); the first was to test the practical implementation of the FlexWood concept in different use cases in cooperation with forest industry partners in Europe, and thus demonstrate its relevance. Demonstrations were arranged in four European countries representing different forest types and ownership structures as well as different forest use practices: France, Germany, Sweden and Poland. The second task aimed to evaluate the FlexWood concept. More specifically, it was to assess the ability of new technologies (mainly LIDAR) and optimized planning systems to make the Wood Supply Chain more efficient at an acceptable cost. This evaluation was based on four demonstration sites where new technologies were implemented. Although these results may not be generalizable and will be specific to local situations, some recommendations for the implementation of new technologies according to the types of sites were made.

3. Main Science and Technology results / foregrounds

3.1 WP 3000 Meeting Industrial Requirements

The main objective of WP 3000 was to express and to describe the demands of main industrial sectors within the Wood Supply Chain (WSC) in terms of wood raw material qualities. It covers production of solid wood products (sawmills), pulp and paper (fibre) and bio-energies. It is often observed that industrials of the WSC must produce on any wood materials available and delivered, where wood raw material pushes the manufacturing of certain products. Combining industrial demand with new technologies such as remote sensing, which enable to identify wood properties early in the chain, opens the door for more efficient processes and material uses.

This WP identifies the profiles of demand of three sectors on wood raw material properties according to their relative importance. The profiles are strongly related to particularities of each production site. Therefore the results are to be seen as representing the typical, general characteristics of industrial requirements that can be expected in an average situation. The profiles of demand are determined by sector specifications, products made and processes used.

There exist several key quality properties of wood raw material for each industrial sector. The requirements are characterised by wood properties at stand level and at individual tree (log) level. Sometimes these properties are shared among sectors (e.g. species), but most of time their relative importance vary (e.g. age). Typical requirements of sawmills are higher than those of bio-energy producers. In pulping, the basic, unconditional requirements vary depending on the type of pulping process (i.e. mechanical vs. chemical pulping). In general requirements are more difficult for mechanical than for chemical pulping. The importance of quality properties is expected to increase in future.

Beside the native wood properties, there are several activities along the supply chain affecting the quality of wood (e.g. harvesting, forwarding, stocking). In general for bio-energies their impacts may be more important than the native properties (e.g. grades, contamination with other materials …). Industrials expect suppliers to improve their efficiency. For a supplier this includes the ability to solve a puzzle of several parallel harvesting objects to serve several customers in time and quantity under variable harvesting and transportation conditions. It can be achieved i.e. by improvements of harvesting and transport techniques, of information systems and logistic planning.

Regarding the quantities of wood, the major consumption of round wood is realised by sawmills, although the level vary among countries. It is reasonable to expect that productions of sawmills and bio-energies will increase at the horizon 2020. Therefore the more the demand of sawmills (having the highest requirements of wood qualities) increases in the future, the more identification of wood quality properties at the beginning of supply chain is relevant, and make the use of remote sensing technologies attractive. Similarly, the more the demand of bio-energies (representing high requirements on activities of supply chain) increases in the future the more efficiency of logistics and material supply is relevant.

Finally, the industrial sectors are not operating isolated in the WSC. Interactions are numerous, and other actors intervene. A stakeholder analyses reveals that there is a potential conflict between material and energy use of wood. The support for Renewable Energy Sources (RES) may lead to shortage of wood and increase in competition within the supply chain. Here also the remote sensing technologies, and logistics, can improve the efficiency of the wood use and as such improve the visibility of the forest based sectors in the sustainable development of Europe.

3.2 WP 4000 Integrated Forest Inventory Design for Optimised Quality and Quantity Assessment of Wood Resources

Introduction

The overall objective of the Flexwood project is to build a novel logistic system ('Flexwood') to optimize information flow in the wood supply chain and thus produce more accurate and timely knowledge for decision making. In order to design and implement such a system, novel concepts and measures for information assessment, information flow and the integration of existing technologies and tools are necessary. The basic inputs required by the Flexwood system are the forest information (e.g. tree diameters, species, limited quality information) collected in traditional field inventories. Different remote sensing techniques are correspondingly expected to provide geographically accurate and detailed information on wood qualities and quantities. Within the Flexwood system, the use of advanced sensing technologies allows a better understanding of the forest resources at lower costs compared to traditional field inventories.

Work Package (WP) 4000 (tasks 4100–4300) developed an integrated forest inventory design for optimized quality and quantity assessment of wood resources. The main objective was to use remote sensing data from both aerial (ALS) and terrestrial (TLS) laser and optical technologies (multispectral and hyperspectral images) to obtain advanced quality and quantity information on wood resources measured in the forest with the novel technology. The specific research objectives were

- to develop and optimise ALS and TLS methods for assessment of wood quality and quantities at high spatial resolution and validate these methods, and
- to optimise the combination of different data sources, such as ALS, TLS, existing geo-spatial data, optical sensor data and field measurements, in description of tree and wood properties.

WP 4000 produced output to be used by later Flexwood work packages in defining optimisation models for tactical and operational planning (bucking, harvesting, allocation of wood) (WP 5000), and optimisation models and enhanced processes for novel and more flexible concepts for mill production (WP 6000). The measures developed within WP 4000 were enhanced and tested for their effectiveness and efficiency in the framework of defined use cases (WP 8000).

The approach

The different sensors can be seen as complementary data sources, so that the airborne data provide a wall-to-wall coverage of the study area and TLS data and/or field measurements provide a detailed description of tree quality attributes on a sample basis. The analyses may be performed at the level of individual trees or directly at an aggregated level (e.g. plot / stand) independently on different data sources. Within the Flexwood project there is a particular interest in combining the area-based and tree-level laser scanning approaches in order to derive forest information (both quantity and quality). There is a prior need to develop both ALS and

TLS methods with respect to these requirements, including integration with other remote sensing data sources and calibration field measurements, for example.

To achieve these objectives, the work package was structured into three separate components, these being wood resource assessment using airborne data (WP 4100), TLS data analysis for obtaining detailed stem information (WP 4200), and integration of these data sources (WP 4300). The experiments were carried out on four separate test sites located in Germany, Sweden, Norway, and Finland. The test sites had various coverage of field measurements and corresponding remote sensing data, including ALS data, TLS data, and multispectral and hyperspectral image data in varying resolutions.

The work carried out within WP 4100 developed components of single-tree inventory by airborne data. In the method development, a particular focus was set on tree species recognition, which was identified as an important yet challenging attribute to be estimated by means of ALS only. Combinations of ALS and spectral information were tested on several study areas to improve tree species estimates. In addition to tree detection, the validation was performed with respect to species, stem dimensions, and branch height properties. Area-based estimation of biomass, volume and species proportions was carried out, and the area-based technique was used to detect stands with a high economic value.

WP 4200 aimed at accurate measurement of the tree stem characteristics applying TLS data. In the work carried out, a selection of trees was scanned applying TLS prior to cutting. The work developed process steps to gain information about the geometrical parameters (position, dimensions) and bark quality of the trees by TLS data. The measured trees were later felled and measured by computer tomography for their internal wood properties (WP 6100). Quality information of the felled trees processed by use of the laser data were linked to quality criteria of computer tomography.

The work of WP 4300 focused on integrating the analysis of TLS-based forest inventories into ALS and/or aerial images based inventories. The method development related to linking ALS and TLS datasets from the same area. A more general aim was to describe a methodology on how to integrate tree and wood properties from different sources to provide sufficient data as input into a novel logistic concept (WP 5000).

Obtained results

A summary of the obtained results is shown below. The figures are best-case accuracies, which vary depending on the properties of the data and the study area. The errors are either classification accuracy or root mean squared error.

A summary of the tree-level accuracies:

Attribute	Test site	Data source	N	Absolute error	Relative error
Species	Sweden	hyperspectral	108	-	21–62 %
	Norway	ALS	1520	-	23–26 %
	Norway	multispectral	1520	-	21–29 %
	Norway	hyperspectral	1122	-	12–16 %
	Norway	ALS + multispectral	1520	-	9–12 %
	Finland	ALS	2985	-	9–12 %
Stem volume	Germany	ALS + multispectral	178	221–525 dm^3	24–57 %
	Finland	ALS	2985	103–148 dm^3	35–51 %
Tree diameter	Germany	TLS	14	0.50 cm	1 %
	Finland	ALS	2985	2.9–3.9 cm	15–30 %
Tree height	Finland	ALS	2985	0.7–1.6 m	4–9 %
Crown base height	Finland	ALS	2067	1.5–1.8 m	15–18 %
Dead branch height	Finland	ALS	2067	2.8–3.7 m	85–112 %

A summary of the plot-level accuracies:

Attribute	Test site	Data source	N	Absolute error	Relative error
Biomass	Germany	ALS	374	54 t/ha	35 %
Proportion of conifer trees	Germany	ALS	374	-	17.5 %
Total volume	Germany	ALS	374	96 m^3/ha	33 %
	Finland	ALS	79	33–38 m^3/ha	17–19 %
Diameter distribution	Finland	ALS	79	EI 832–834	-
Tree detection	Finland	ALS	79	-	44 %
	Germany	TLS	23	-	16 %
Tree position	Germany	ALS		1.6 m	-

Tree species classification accuracy was dependent on the applied estimation technique and data source. The classification could be performed based on a single data source, but in the tests carried out at the Norwegian study area, the results were improved by an integration of different data sources. In Sweden, the accuracy of the classification was tested only on two test sites, of which the site with the lower accuracy was purposively a difficult target. Despite, the variation between the sites shows the limitations in the applied methodology. In Finland, an accurate species classification result was obtained using structure and intensity features obtained solely from ALS data. However, the differences in the species composition between the study areas should be taken into account when comparing the results. In the Finnish study area, pine trees were the dominant species and formed even pure stands, whereas the species proportions were more evenly distributed in the other areas.

Stem volume prediction was tested on two separate study areas, which gave different results. The absolute error levels were higher in the German test site, where also the trees were larger, resulting in lower relative error rates. In both test sites, the estimates were found to vary highly depending on the model form or the parameterization of the nearest neighbour technique used. The best obtained results correspond with those reported earlier in Germany and Scandinavia.

ALS-based tree diameter (DBH) and tree height estimates had a very similar accuracy compared to previous studies carried out in similar conditions. Also the crown base height was estimated with a similar accuracy than earlier, and this estimate could be only slightly improved from the direct measurement by including field data in a MSN imputation. On the other hand, the dead branch height correlated moderately with the ALS features, and was predicted with a low accuracy.

Using TLS data, the DBH could be estimated with an accuracy of 0.5 cm (1.3 %) for the 14 trees identified clearly and scanned from multiple directions. However, the automatic procedure for detecting the trees did not find all trees (success rate of 84 %), the probability of tree detection decreasing with an increasing distance to the scan centre. In ALS, the tree detection rates tested were at the same level than in an earlier comparison of the tree detection algorithms.

Plot-level biomass and total volume estimates had a relative error of 33–35% in the German test site and 17–19% in the Finnish test site. The difference between the estimates is likely attributed to the used estimation units, which were considerably larger in the Finnish test site, and overall differences in the forest structure. The deciduous forests are indicated to be more challenging towards the ALS-based estimation in the previous literature. In the Finnish test site, realistic diameter distributions were obtained based on ALS data and single-tree imputation, yet the distributions were truncated due to not detecting all the trees. Unbiased estimates were obtained by the tree-list imputation technique. In the Finnish test site, also species-specific plot-level volumes and diameter distributions were evaluated. The species-specific estimation was found to be less accurate compared to total attributes, yielding accuracies 35–39 %, 67–105 %, and 93–108 % for pine, spruce, and deciduous trees, respectively.

Conclusions

The obtained results suggest ALS as a useful data source for estimating attributes for the trees dominating in the forest canopy, and that there are several established techniques for performing the tree-level analysis. The attributes extracted directly include the number of trees and their positions at the plot-level, and tree height and crown attributes such as width (or diameter or area), volume and length for each detected tree. The extracted attributes can be further used in estimating other tree attributes based on an allometric system of models. These direct estimates should be treated with caution, however, as not all trees were detected and the estimates were found to include systematic errors, for example.

By including local field reference data, both area-based and tree-level imputation techniques can be used to produce unbiased estimates for the attributes of interest. Besides estimation, the area-based technique was found useful for detecting stands with a high economic value, and thus allocating field measurements, for example. The predictable attributes include total volume, biomass, and proportion of conifer trees. Also species-specific plot-level volumes and diameter distributions can be predicted based solely on ALS data, at least in areas with fairly simple forest conditions and species composition. The species-specific prediction can be improved by integrating ALS with optical data from multispectral or hyperspectral images, which improve the classification result especially with respect to the proportion of deciduous trees.

TLS was found to be an effective sample-based measurement technique, enabling DBH measurements with an accuracy comparable to manually performed calliper measurements. Also, comparison to manual measurements indicates a potential to identify bark characteristics from an intensity image based on the TLS data. These measurements and their connection to the interior wood quality were also verified. However, these results were based on only 14 trees scanned from multiple directions, while an automated analysis of the single-scan TLS data showed less accurate results. Not all trees could be detected and the analysis showed a tendency to underestimate the DBH. The probability of tree detection decreased with an increasing distance to the scan centre. Thus, further developments are needed to optimize the integrated use of TLS data with airborne data sources, particularly linking TLS detected trees to ALS and using this information as carried data.

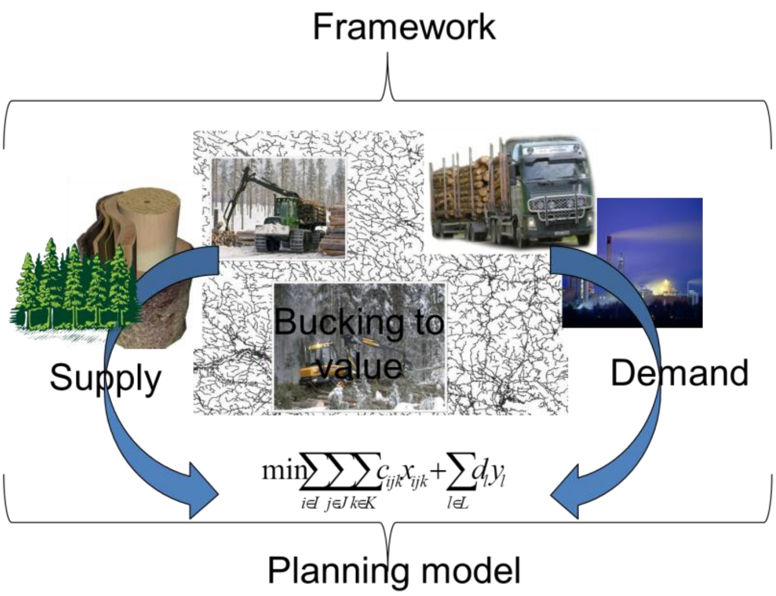
In addition, the work in WP4000 indicated and developed promising research areas and techniques that need further verification. Examples are stem detection algorithm based on high-density ALS data and using TLS shape distributions as training data for ALS analysis. Also the calibration of the airborne data-based estimates using a limited sample of field data requires further testing, and as most of the techniques rely on the use of field data, the amount of field sample plots required for reliable estimation should be generally further studied

3.3 WP 5000 Novel Harvesting and Logistic Concepts for Integration of Forestry with Industry

The results from WP 5000 are reported in D 5.4.

The objective for WP 5000 was to develop and evaluate novel logistic concepts able to match industry demand with forest resources under varying conditions.

Results from the five tasks in work package 5000 are core modules building a novel logistic model for efficient wood supply integrating forestry with industry.



Overview of work package 5000. First we developed a generic method to describe and measure different wood supply systems (task 5100). According to that we also described the special circumstances for small private forest owners situation in central Europe (task 5200). Then we described data needed to build a planning model, especially supply descriptions of forest stands via laser scanning and industrial demand (task 5300). We also looked into more flexible means to adapt the bucking processes in the cut to length harvesters (task 5400) and finally developed a planning model to match industrial demand with forest supply efficiently using operational means i.e. harvest- and transport equipment and road network.

To reach a better understanding of the structure of different Wood Supply Systems we developed a framework to describe alternative logistics concepts. The configuration of the main stakeholders and planning systems to provide higher agility and tailoring within the wood supply chain was described. The work is presented in d*eliverable 5.1, General framework for describing different wood supply chain systems, responsible partner is Université Laval (Task 5100). In connection to describing different Wood Supply Systems we also* mapped and analyzed the structures of forest owners, available forest data, preferences and information requirements in the test areas. Specially, the small forest owners perspective was analyzed. This work was carried out by FoBawi (task 5200).

To be able to match industry demand with forest resources the structure the data on industry requirements towards forest raw material on the one hand and of the forest resource from novel inventory technology on the other. Different inventory concepts have been alternatively developed in the Flexwood project and are applied in the different use cases. Therefore the matching procedure may (technically) differ from case to case. *D 5.2 Others (Month 24): Interfaces and procedures for existing harvesting and logistic concept.• Responsible participant: ALU-FR-FobAwi*
We analysed how the bucking optimization could be controlled and developed according to increased agility in relation to specific industrial demands (WP 3000, WP 6000) and the improved information on the standing trees (WP3000, 4000 & 5400).

To be able to develop Forest Industry Value Chains we created a new optimisation model for both tactical and operational planning and bucking that can adapt (tailor) the wood supply from the standing forests to different demands from sawmills, pulp & paper mills and combined heating & power plants. *D 5.3 Others (Month 24): Software and optimisation models for novel logistic and harvesting concepts.• Responsible participant: Skogforsk*

Finnaly the workpackage was summarized in *D 5.4 Others Novel Logistic model – Optimisation model for tactical and operational planning of the logging- and transport operations including data management.*

One objective of FlexWood was to propose a novel wood supply chain (WSC) that increases value recovery through higher flexibility and tailoring capabilities. The objective for WP 5000 was to develop and evaluate novel logistic concepts able to match industry demand with forest resources under varying conditions. To be able to develop such core modules into a demand driven novel logistic concept we divided the work in work package 5000 into five tasks :

In task 5100 a framework for describing different wood supply chains (WSC) in a generic way and assessing their agility and tailoring capabilities was developed. The studied WSC comprised the planning and execution, at the operational level, of all activities, from selling agreements to delivery of forest products at the mill yard. These include the purchase or selection of harvesting blocks, harvesting scheduling and execution, as well as transportation scheduling and execution. The framework includes a set of descriptive templates including e.g. a description of the actors, their planning and execution processes, the decoupling points used, together with information, material and financial flows.

Three basic designs of planning systems were identified: 1) integrated sourcing and harvesting planning, 2) integrated harvesting and transportation planning, and 3) decoupled sourcing, harvesting and transportation planning. We also identified six logistics techniques to adjust supply to demand.

The agility capabilities of the WSC were assessed in four dimensions: customer sensitivity, process integration, information drivers and network integration. A WSC should strive towards proper agility capabilities in response to uncertainty in their environment.

Finally, tailoring capabilities were assessed, based on the location of the decoupling points and their respective order fulfilment cycle time. Two processes were identified, where most of the product differentiation activities along a WSC occur: harvesting with the CTL method and merchandising at a roadside landing using the FT method. The capabilities to tailor product specifications are superior before rather than after one of these processes.

In task 5200 we studied harvesting in small private forest ownership in Europe. Currently, the share of private forest ownership in Europe is around 50 % with great variations between countries. Set in the context of forest industry, logistic concepts are usually developed for larger entities of forest ownership or integrated forest industry. In order to cope with other property conditions, which account for a large share of the forest resource throughout Europe, we investigated specifically how small private forest ownership could be tied to these concepts.

The divergence regarding small private forest ownership throughout Europe is high, not only due to variable definitions of small-scale forestry within European countries. Thus regional circumstances need to be considered and have to be scrutinized case by case to see how small non-industrial private forest ownership can be integrated in advanced harvesting and logistic concepts such as Flexwood. This relates to the widely discussed topic of wood mobilization and constraints in private ownership, which arises amongst others from the fact that for instance in

Austria and Germany the ratio between increment and felling is significantly higher in small private forests than in larger properties.

Novel logistic concept are particularly attractive where forest function and ecosystem services are segregated from each other (e.g. plantations) and in timber-oriented, highly mechanized forestry regimes with high levels of accessibility and infrastructure. Furthermore up-to-date inventory and mechanized harvesting systems are prerequisites for advanced data acquisition and transfer, while small holdings lack detailed inventory data and restrict the use of mechanized harvesting systems for various reasons. This may inhibit their participation in advanced wood supply chain systems and may restrict their market access

However, there remain other possibilities. Cooperatives can play an important role as providers for the required knowledge, services and technology. In addition, the modules of Flexwood separately offer large potential for the wood mobilization from small private forests. This is for example the case for the application of novel technologies for forest inventory and the web-based platform approach. These can furthermore be possible tools visualize the potential benefit of the utilization of their forest resource and stimulate forest owners to consider harvesting. This may be especially well-suited to address younger generations of forest owners, which will be an increasingly important aspect in the next years, but is certainly not limited to that.

In task 5300 procedures and processes for the allocation of forest raw material to the industry was described. It builds the link between industry and forestry. Basis is on the one hand the data on the industrial requirements towards forest raw material; this has been elaborated in WP3000 and WP5300 and on the other hand the data on the forest resource from novel inventory technology - the outcome of WP5300 and WP4000. Following the principle of demand-driven wood procurement, starting point are the industrial requirements, which are converted and condensed into an appropriate format, common across the participating European countries which contains both dimension and quality information.

In a second step the results of the inventory based assessment of the existing forest resources are converted into a format, which is compatible to the list of requirements.Technically different inventory concepts have been alternatively developed in the Flexwood project and are applied in the different use cases. Therefore the matching procedure may (technically) differ from case to case Impact and possibilities regarding market conditions and different suggestions for developing the interface industry – forestry when operating forestry within a Cut-To-Length system is described as the Nordic perspective.

In task 5400 we analysed how the bucking optimization could be controlled and developed according to increased agility in relation to specific industrial demands (WP 3000, WP 6000) and the improved information on the standing trees (WP3000, 4000 & 5400). Ideally, the bucking process should be a fully integrated, efficient part of each industry. As the wood flow becomes controlled by advanced logistic tools, it becomes increasingly important to support the system with an efficient bucking control, including description of the logs by individual characteristics and predictions of total product yield. To achieve the objectives of a novel logistic concept, the system need new tools for automatic and more flexible bucking control, with respect to alternative customers' and pricelists in question for specific harvesting objects

In task 5400 we supported the Flexwood scheduling optimization module with adapted production data in a standardized format according to StanForD 2010 and adapt and test the control messages to control the harvester with production instruction according to the needs calculated in the novel Logistic Flexwood scheduling optimization tool. The control messages shall follow StanForD 2010.

This means that the goals of WP5400 were primarily to improve two parts of the "Novel logistics" chain: 1. bucking simulations that generates improved detailed production data that can be used in the logging scheduling optimization and 2. Controlling production at individual sites through a significantly more flexible bucking.

The present standard for communicating with forest machines, StanForD, does not support the possibility to update or modify product instructions in the harvester in a very flexible way. The work in WP5400 has therefore partly been to develop a concept for a more flexible bucking control which has been used when implementing a totally new standard version, StanForD2010. The new StanForD2010 standard thus supports a more flexible bucking.

In task 5500 we have developed a solution approach and models aimed to schedule harvesting resources (i.e. harvester, forwarder and harwarder) in combination with the selection of stands to be harvested under restriction of fulfilling demand from industry and minimizing the overall logistic cost. The purpose was to create an operational plan on which stands are to be harvested when in time and by which harvesting machine team. The logistic cost includes costs for harvesting, transportation of round wood from forest to mill and moving machines between stands. The outcome of the harvested stands (volume per assortment) was matched with the demand from pulp-mills, sawmills and CHP-plants.

In order to get the right outcome from the stands the solution approach suggested which bucking instruction to be used for each stand.

3.4 WP 6000 Flexible and Customer Adapted Mill Production

WP leader VTT, participants: FVA, Skogforsk, ALU-FR FobAwi

Objectives of WP 6000

1. To collect data (e.g. scanning technology) to provide information for modelling the manufacturing processes (saw mill and secondary conversion) and further on to final products (sawn timber and value added components)
2. To create concepts for converting wood raw material into sawn timber and wooden components through radically more flexible manufacturing processes than in the current situation.
3. To integrate the forest optimisation models from WP 5000 into conversion models

Description of work and outcomes:

Task 6100: Data collection including scanning of logs and sawn timber.

Task leader: FVA

Eight beech logs were sawn into quarters to determine the maximum diameter of hardwood logs for appropriate image quality from CT-scanning (Fig.1). 26 beech trees were felled. The outer appearance of these trees was assessed and all branch scars visible on the bark were measured. Then, the trees were CT-scanned and the knot sizes were measured manually in the CT-images. This gave a large data set to confirm the correlation between branch seal quotient and the knot size. Destructive measurements with radial cuts were performed at 26 branches for CT validation. Twenty trees (40 logs) were sawn to boards of even thickness for appearance grading. All CT-data (outer shape of log and inner properties such as knot size and knot condition) was stored in a format that allowed VTT to perform sawing simulation and grading of the virtual boards.

Significant results

X-ray artefacts were sometimes visible in CT-scans of logs of a diameter larger than 40 cm, however the accuracy of knot measurements was not reduced as the analysis of scans from quartered logs could show. The shape of branch scars is directly related to knot size and the amount of knot free wood and therefore product quality. A linear regression analysis of 666 knots could confirm a strong correlation (r^2=0.63) between branch seal quotient and the amount of knot free wood derived from CT images.

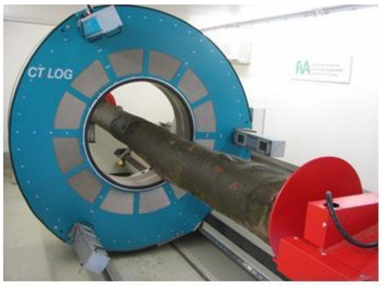


Figure1. CT-scanning of a log.

Manual measurements on radial cuts could show a high precision for the total length of manually measured knots in CT images.

Task 6200: Modelling of conversion chains from wood raw material to wood products

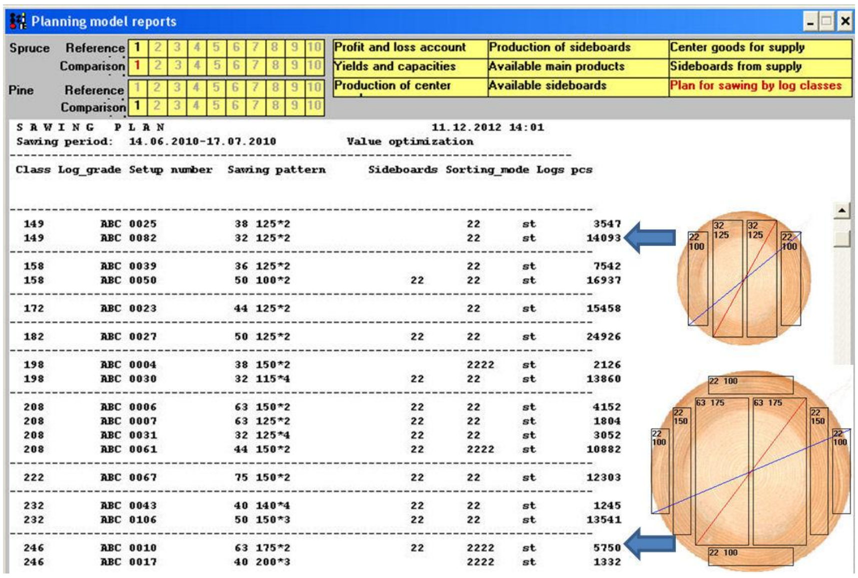
Task leader: VTT

There are many phases and number of operation options in wood conversion chain between forest and final products and end users. The importance of right decisions increase by coming closer the forest because it's not possible to correct later mistakes made in earlier phases of conversion. Because of huge number of production parameters human planer needs means to support his decision making. Software tools based on scientific modelling can provide strong fundamentals decisions. However it's always human planer making the final decision.

Modelling is based on simulation and optimisation approaches. Linear and dynamic programming methods will be used. Starting point in the development is VTT's WoodCIM® model system which is used in the industry and scientific work. There are two main models and software

1. Simulation and optimisation of sawing set-ups for individual logs and log classes (Sawing simulator)
2. Optimisation of activities within planning periods (Sawing model)

Sawing simulator predicts volume of sawn timber by dimensions and grades, wooden chips and sawdust when sawing a log or class of logs using different sawing set up options. (Figure on following page). **Sawing model** links together sawn timber demand and available logs taking into account production constraints i.e. capacities, trying to achieve maximum value of object function i.e. profit within a time period to be planned.



Output from Saw model. Number of logs to be sawn using certain sawing pattern.

Sawing simulator and sawing model where installed at VTT's Server platform. They were available for simulations through central server in Ireland. Calculations were successfully realised. The models were used to calculate, evaluate and develop process options. Modelling and simulation software can be used to determine exactly how the wood raw material can progress from trees to timber and wooden components in the most economical way. Wooden components are special timber, i.e. timber with precisely specified properties. Typically components are used for secondary conversion to become part of products like a window frame. For example, a piece of wood used for such a purpose must be completely knotless, or have a knot incidence within specified limits. Also, wooden components are usually much smaller than pieces of timber; there are also specifications for knot incidence in ordinary timber.

Task 6300: Improving flexibility in production and future manufacturing systems

Task leader: VTT

Flexibility is important character of future manufacturing processes. This demands the possibility to switch from bulk production to manufacturing of value added components and opposite way. New flexible manufacturing concepts were created and evaluated through simulations using Sawing simulator and Sawing model created in task 6200. Economic analysis was carried out the determining of impact on profitability i.e. mismatch between log order (diameter-length distribution) and delivered logs.

Significant results

*****Main issues in the flexible production system are**:***

Value added components and upgrading of sawn timber into components with flexible and adaptive manufacturing systems for sawmills. Producing value added components with customer's specified dimensions and quality features instead of standard products offers sawmills big potential to improve profitability of business. Production of components should be started directly from the logs.

Cross cutting of stems and sawing method.

Best bucking and cross cutting result can be achieved when the stems or part of stems are transported to cross cutting station provided by x-ray scanner and advanced optimisation software.

Information systems and intelligent material flow control. In individual phases of conversion scanned or measured data increases rapidly. However this information is utilised only locally and then dumped. This happens all the way throughout the supply chain. It is not possible to link final products, raw materials and processing parameters together. Strong support for business development can be achieved if the lost information can be stored and utilised in the later conversion phases. Recovery of information can be achieved through marking pieces, reading of the markings and storing the data in a database for utilisation in different applications

Scanning of internal properties of stems and logs for characterisation wood raw material and optimisation of sawing operation.

Log scanner systems for measuring shape and internal properties of logs can be used in the following processes: Log sorting station for optimisation of borders of log classes; Cross cutting terminal for optimised of cross-cutting of stems; Just before sawing for optimisation of log rotation angle and sawing set up for individual logs.

X-ray scanner can detect properties of round wood. The analysing software should be tailored to meet application requirements. Typical functions can include measuring of dimensions/volume, moisture content, volume of knots, rot and other defects and heartwood/sapwood ratio. In the future it's possible to full description of wood properties i.e. individual annual ring structure and density profile.

The project results show that there is scope for considerably better exploitation of the wood material and its quality properties in production. Product quality could also be improved, and special products could be manufactured instead of standard ones. Process re-engineering can yield a considerably improved financial performance. In fact, the value yield of wood could be improved by 10 to 30 per cent with modern production methods.

An advanced production process requires careful measuring of the properties of wood, for example 'X-rays', the efficient collection of measurement data and their conversion into information that can be used for business management. Measurement data enable the allocation of incoming timber to a suitable production process at an early stage.

Sawmills could serve wood processing companies better by adding services to their products. For instance, they could issue their customers instructions as to how and for what purpose a particular delivery should be used. An even more advanced service would be to measure the properties of the outgoing timber in detail at the sawmill, for instance the precise location of knots or the grain pattern of the wood. The wood processing company could then use this information in its own production process as it cuts the timber up into wooden components. In other words, the wood processing company would not need to measure the timber all over again, as the producer would have tagged the timber with RFID tags, for instance, and provided the customer with a chart of the properties of the batch.

This technology improves production flexibility, as production lines can be reallocated from bulk products to special products and back again, as the market situation dictates. Changes that improve production efficiency can generally be implemented at a relatively low cost. Indeed, optimisation of timber sorting and sawing patterns could be introduced immediately in existing processes, without any substantial new investments. The WoodCIM® modelling system developed by VTT is already in use in the industry. New sawing methods, such as efficient through sawing, could be introduced when investments are made in new sawmill production lines. Precise measuring of the inner quality of wood still requires further research.

Task 6400: Interface to connect manufacturing systems with novel logistics concepts and wood raw material

Task leader: VTT

Conversion models create relevant information about optimal allocation of wood raw material specifications and requirements (diameters, lengths, qualities etc. – order towards forest) and cross-cutting rules and instructions. Models also strongly support sales activities, selection of orders, customers and product development. Integration between conversion model system and other FlexWood model systems i.e. harvesting has been realised through Central server system.

3.5 WP 7000 Communication Infrastructure for the Support of Increased Wood Supply Efficiency

The role of the WP7000 in FlexWood was to deliver and implement an architecture to provide the IT infrastructure for collaboration of many forest related services. This collaboration is a key to the success of the FlexWood project as it allows a complete integrated model of the forest supply chain to be achieved. Only by bringing the various services together can there be a synergistic effect, to realise many new types of knowledge which can be determined before, during and after harvesting. The other important aspect of the architecture is the multitude of potential stakeholders in different locations capable of using the system. The architecture must therefore support multiple views of the operations and data from a wide variety of devices. Therefore, only certain functions and results are available to each stakeholder.

We have adopted a distributed web service based architecture with centralised controller. Therefore each partner's software is packaged as a web service with strict published input and output formats through xml files. The web service is hosted on the partner's web server and can be independently maintained and developed. The cueing in of each of these services is determined through the FlexWood portal user interface and its controller service. This function decides the appropriate service(s) to invoke (with data) provided that the user has described the correct input. This open xml format also allows other web services to be plugged in, where national or regional ways of operating need to be respected.

Figure 1 and Figure 2 show the various components making up the entire architecture of FlexWood. The implementation uses JavaScript, SOAP, Ajax and HTTP – all standard open software components for building a distributed, interactive web-based system.

In Figure 1, the users at the top interact over http with the FlexWood user interface and controller to view information and to build scenarios to be passed to various simulation services.

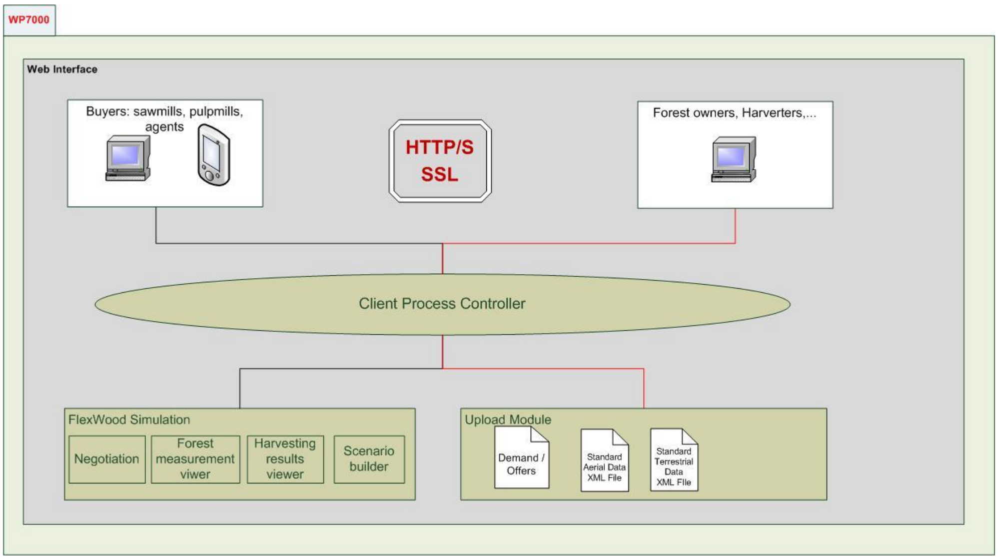


Figure 1: Process Controller Web Service and Interaction with the User Interface

In Figure 2, the simulation services are broken down into types and responsibility of work package. The controller web service is the interface between the user specifying some action in the UI and it being carried out. There are four main interfaces with other forest web services from the controller. The first is to the measurement web service WP4000 which provides data and visualisations on forests, stands and stems. The second service is harvesting, which primarily provides a simulation service for stem files and returns the expected log output volume by length. This service also provides a catalogue of APT files which the user can select (through the FlexWood interface) as input to the harvest simulation. A third service concerns scheduling harvesting. This is an optimisation service which accepts as input the stands to be harvested, the resources to carry this out and location information. The service then returns a schedule to describe the sequence in which each stand is harvested and by which team. The fourth service is the sawmill simulation, which accepts a set of logs and applies a cross-cutting pattern to return a set of end products. The cross cutting patterns are accessed via the same web service, for users to make a selection.

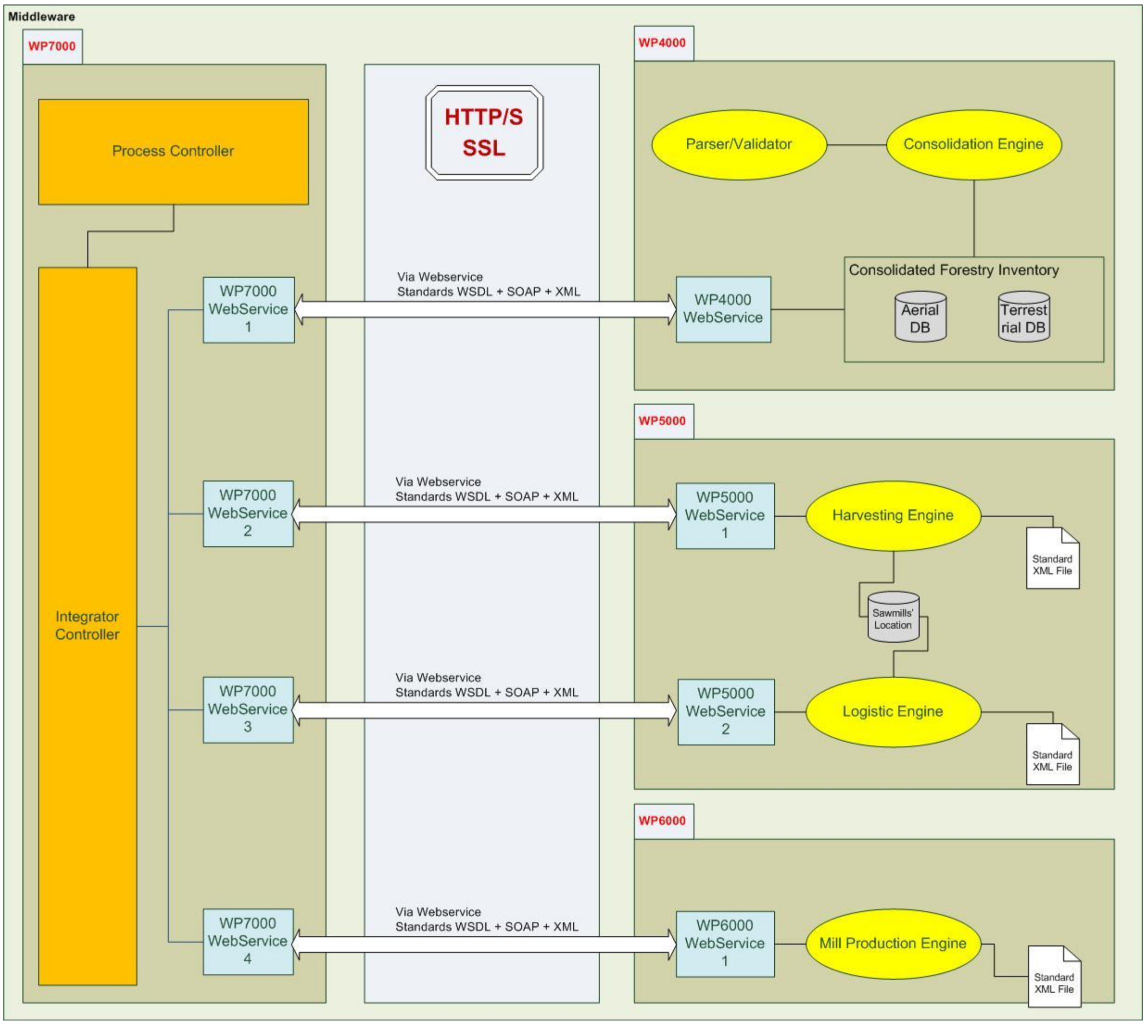


Figure 2 : Process Controller Web Service and Interaction with other Forest Web Services

There are number of integrated web services making up the FlexWood system. Each can only be invoked by the stakeholder through the user interface. The main web services and descriptions are, Controller, User Interface, Measurement, Harvesting, Logistics/scheduling, Sawmill Cutting.

3.6 User Interface

The user interface needs to support the stakeholders in the different case studies to carry out what they want to do. Part of the objective of the UI is to help the stakeholders reach a specification of their problem – we do this by presenting a number of forest entities and ways of combining them into scenarios to be passed to the appropriate forest web service. These entities are instantiated to actual forests, stands, sawmills, etc.

The UI shows basic information on location, number of trees and number of stands (Figure 3).

Figure 3 : Information on the Karlruhe Forest, Germany

The user needs to be able to carry out certain simulations with the software and these are typically quite complex in terms of the inputs and outputs. Therefore separate scenario builders are made to compose the input and viewers to display the output.

The user interface now presents the “Scenarios” area where all harvesting and sawmill simulation scenarios will be constructed and evaluated. Figure 4 shows the initial scenario window presented to the user. There is a natural sequential order to the simulations and these are reflected in the order of the buttons. Each stage can be saved and restarted later.

Stage 1. Load STM files – this button invokes a query on the harvester web service for all known and named sets of stem files. The results are shown in the “Stem Files” menu.

Stage 2. Load APT files - this button invokes a query on the harvester web service for all known and named APT files. These are files which have been pre-generated, for example by the forest owner, harvesting company or sawmill. The results are shown in the “Stem Files” menu.

Stage 3. Harvest Simulation – this button invokes the harvesting web service on the selected STM and APT files. A breakout file is generated as a result and displayed through the UI.

Stage 4. Sawmill Simulation – this button invokes the sawn products web service on the selected STM and APT files. An end products file is generated (and breakout too) as a result and displayed through the UI.

These 4 steps are presented in the Scenarios interface (*Figure 4*) through appropriate button press and menu selections. Notice that different inputs can be segregated through the use of the Scenario tabs.

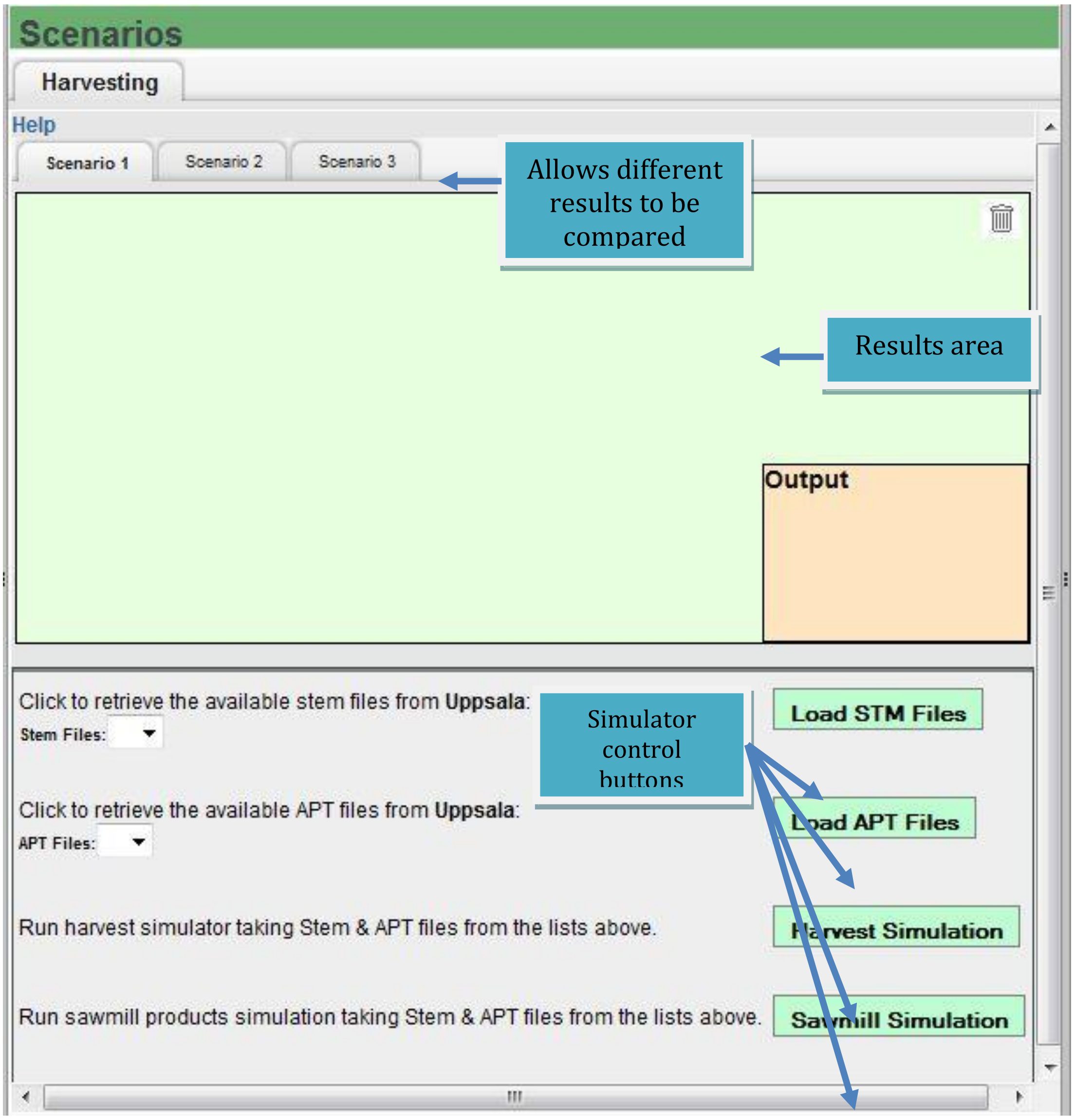


Figure 4 : Main Page for Scenario Building and Simulation

The results of the harvesting simulation is a breakout shown in Figure *5* where different volumes of log lengths are presented to the user.

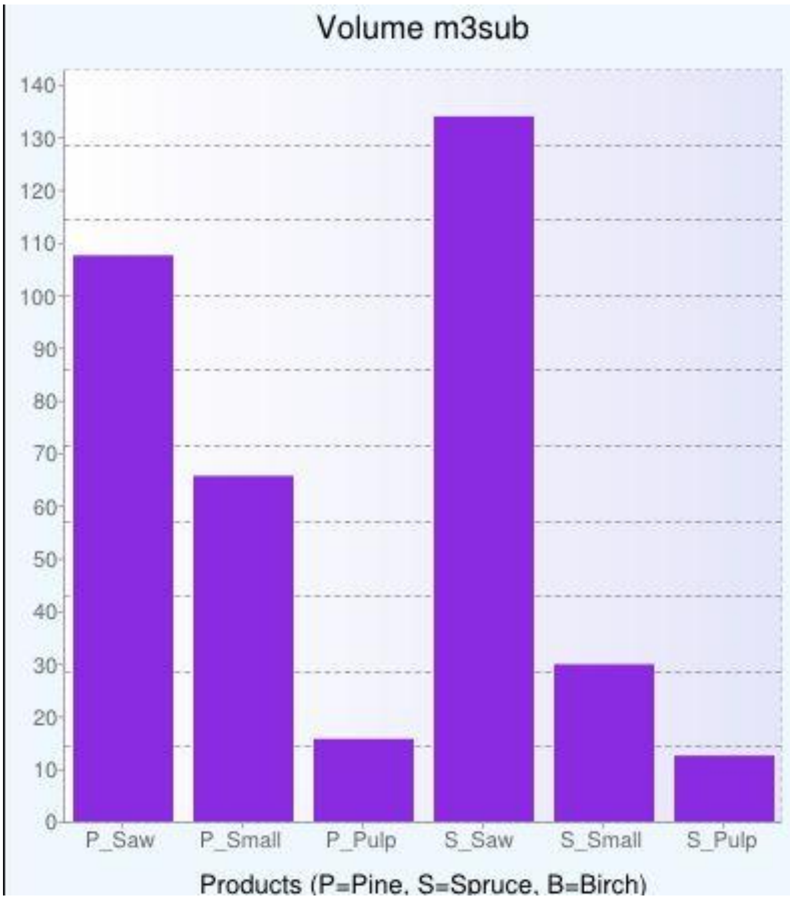


Figure 5 : Breakout Results of Harvest Simulator

3.7 WP 8000 Implementation and Demonstration of the FlexWood Concept

Task 8100 Use case implementation and testing of FlexWood system

The overall objective of the FlexWood project was to build a novel logistic system, which would provide value recovery along the wood supply chain. By integrating improved measurements of standing trees with tools for planning harvesting, cutting and supplying forestry products, the goal was to improve the fulfilment of industrial requirements in terms of value and efficiency.

In this research perspective, the objective of the study cases (WP8000) was to test the practical implementation of the FlexWood concept in cooperation with forest industry partners in Europe, and thus demonstrate its relevance. Demonstrations were arranged in four European countries representing different forest types and ownership structures as well as different forest use practices: France, Germany, Sweden and Poland.

France

In France efforts were coordinated to translate the FlexWood concept into an integrated set of tools for harvest planning in cultivated maritime pine forest. More precisely, the study case was centered on one of the problematics supply companies have to deal with daily: how to decide on the best harvesting instructions to cut demanded round wood products from an available set of blocks (standing timber).

Germany

In the framework of FlexWood the German use case was designed to represent the typical structures of Central European multifunctional forest management systems: mixed uneven stands with a significant proportion of broadleaf trees, limited and not standardized conventional inventory procedures and results and a diverse structure of wood industry, represented namely by small to medium size saw mills and bioenergy utilization. Furthermore in the FlexWood context, special emphasis was given to a detailed description of industry-relevant round wood and log characteristics (dimensions and quality features) and the possibilities to derive them from advanced remote sensing and information technology.

Poland

The specifics of the domestic wood market significantly influenced the implementation of the Polish use case. The main domestic supplier of wood in Poland for many years now continues to be the State Forests National Forest Holding. The wood it offers is sold to a large extent (90-95% of volume) through various online auctions. Potential buyers bid on auctioned lots of wood of specifically defined quality and dimension parameters. Due to this fact, the Polish use case focused primarily on an assessment of the usefulness of the idea proposed in the FlexWood project, especially the new techniques and technologies used to perform forest inventories and pre-harvest assessment.

Sweden

In the Swedish use case, the aim was to improve the operational planning process by improving the data quality describing the forest, the tools for yield simulation and also the choice of stands according to industry demand, the value of the wood and processing costs. The aim of the project was also to evaluate how a tool for operational planning that includes scheduling can enhance adaptations to industrial demand and how the input data in the system can affect the choice of stands. An additional aim was to investigate whether the forecasts can be improved through the higher accuracy and precision of forest inventory data.

Task 8200 Analysis and mapping of project results

Objectives

The overall objective of the FlexWood project is to develop and to build a novel logistic system, incorporating better information on wood resources and enhanced optimisation models, to respond more efficiently and adequately to the demands of industrial sectors. In other words, the aim is to reach a better matching between supply and demand and to provide a Wood Supply Chain (WSC) driven by demand, where requirements of industries pull the activity of the rest of supply chain, until the forest exploitation (and not the opposite, as still often observed today). Finally, this increased flexibility and the better knowledge of resources must create value throughout the WSC.

In this context, the Task 8200 aims to evaluate the FlexWood concept. More specifically, it is to assess the ability of new technologies (mainly LIDAR) and optimized planning systems to make the Wood Supply Chain more efficient at an acceptable cost.

In order to provide such analysis, the evaluation will be based on four demonstration sites where new technologies have been implemented in the framework of the Task 8100 ("*Use case implementation and testing of FlexWood system*"). These demonstration sites are located in France, Germany, Sweden and Poland.

The approach

Considering the constraints related to the Task 8200 (time budget, data availability, still experimental technology in some cases), the chosen approach to do the evaluation combines qualitative and quantitative analysis.

The qualitative analysis consists mainly to compare the Business as usual scenario and the FlexWood scenario on key points of the WSC and to analyze the main changes, in particular in terms of technologies used and process. Based on this description, the objective is to point out the advantages (already observed or expected), disadvantages and limits to the implementation of the FlexWood concept.

In addition to the qualitative analysis, we have sought to quantify some effects of the Flexwood concept (in particular, the LIDAR technology) through indicators in terms of economic performance, organization efficiency and customer satisfaction. These indicators have been calculated both in BAU and FlexWood scenario.

Obtained results

The evaluation methodology has been implemented in the four Use cases, where the FlexWood concept has been tested (France, Germany, Poland and Sweden). If these four sites have common characteristics (managed and productive forests), they present also differences, in particular in terms of surface, species and homogeneity of the forest resource.

At first, **the qualitative analysis** has revealed that **the LIDAR can enhance the resource information, on both the volume and quality.** In addition, LIDAR allows an automation of data gathering (saving time) and a better homogeneity of the data collected. In particular, ALS is the preferred data source to estimate the geographic position of a tree, which gives information on how many trees that are found within a harvest area. ALS gives also accurate estimates for tree size including height and diameter (DBH) for the detected trees. TLS is especially effective to estimate the diameter (DBH) and the stem taper. Finally, TLS is the best method (with the harvester's measurements) to define the external properties of the tree, that can be used to deduce information about the interior of the stem.

Nevertheless, **the LIDAR technology has also shown some limits**. In particular, that is not effective to provide data on tree age and tree species. ALS could be an alternative approach for detecting tree species but not alone (in combination with other methods). Furthermore, the Use cases in Germany and Poland have pointed out that, with the LIDAR, it is difficult to gain reliable information in case of very heterogeneous forests.

A better information of the forest resource alone is not sufficient to improve the entire WSC. **The optimization of the new data collected implicates also changes and improvements at the different stages of the WSC** (stand allocation, harvesting, logistics, demand requirements). Some Use cases (mainly Sweden and France) have tried to implement novel solutions in planning systems to optimize the logging operations and to improve the bucking simulations and harvest instructions. Furthermore, the French Use case has worked to develop enhanced round wood specifications that industrial users could use to express their expectations. If first positive results have been already observed, more developments and improvements are still needed (see Annex).

Concerning **the quantitative analysis**, **except for the Swedish Use case, the implementation of LIDAR implicates higher inventory costs than those in BAU**. **All the other indicators, in contrast, are improved** (or expected to be improved) in the FlexWood scenario. The best results are obtained for the "*time deliver*" with an important decreasing of the time needed to deliver the customer between the BAU and the FlexWood scenario. Other indicators should be significantly enhanced according to the Use cases : the "*productivity*" and the "*monetary optimisation of product mix*" in the Swedish Use case, the "*customer satisfaction*" in the French Use case. However, concerning the "*storage rate*", just a slight improvement is expected in the FlexWood scenario, as the congestion may not be completely avoided compared to BAU.

The results can be summarized in the following SWOT Matrix:

Strengths	**Weaknesses**
Better resource information (volume and quality)	Difficulties to obtain precise species through LIDAR technology
Useful in monocultural forests (e.g. pine forests)	Difficulties to gain reliable information for very heterogeneous forests (e.g. German Use case)
Enable the mapping of large areas in a short time (ALS)	High costs of LIDAR implementation for small areas (e.g. German Use case)
Lower unit costs for forest inventory based on ALS at a large scale implementation (e.g. Swedish Use case)	New technology which still requires improvements for collecting and processing the data
Better productivity for stand allocation operations and for planning harvesting	
Decrease of storage rate in forest and roadsides	
Better customer satisfaction	
Enhanced product mix	

Opportunities	Threats
Supply-related jobs could become more attractive LIDAR data collection could be a collective dynamic within the forest sector or with others actors (agriculture ?) One component in strategy to respond to possible future wood shortage and/or price increase	Existing personnel might be reluctant to adapt to new technologies Non-optimization of the implementation of LIDAR technology if the information tools and planning systems are not enough performance to integrate LIDAR data Non-optimization of the implementation of LIDAR technology if the other stages of the WSC are not also improved (logistics, wood specifications from industrial actors, communication…)

Based on these results, we can make some recommendations for the implementation of LIDAR technology and the development of FlexWood concept in the WSC :

- The airborne LIDAR **is relevant mainly in case of large areas with a homogeneous forest resource**. In such situation, this technology is cost-effective and provides valuable information for a better resource knowledge ;
- In contrast, it is not relevant for small areas due to high costs of data collection ;
- LIDAR technology is **not well adapted to heterogeneous forests** ;
- **The technology is still new and needs to be improved ;**
- LIDAR technology will be **more relevant in combination with other technologies** (e.g. TLS + Photography) ;
- **The optimization of LIDAR data implicate also changes and improvements in the planning systems and at the different stages of the WSC** (logistics, wood specifications from industries…) ;
- A solution related to high costs of LIDAR implementation could be to share them with others actors. Nevertheless, it is necessary that these actors have comparable needs.

4. Potential Impact, dissemination activities, exploitation

The FlexWood project adapts and further develops existing processes to industrial needs for an improved and flexible wood supply chain under changing conditions. The outcome leads to additional value and improved process efficiency from forest to mill operations. This will provide extensive benefits for forestry and the forest-based industry, where a win-win situation is expected for the many stakeholders involved.

The project has focussed on integrating:

- advanced quality and quantity information on wood resources measured in the forest with novel technology (WP 4000)
- optimisation models for tactical and operational planning (bucking, harvesting, allocation of wood) (WP 5000)
- optimisation models and enhanced processes for novel and more flexible concepts for mill production (WP 6000) and
- improved information transfer between all stages of the wood supply chain to create new knowledge for decision making (WP 7000).

To better understand the specific potential impacts of the project, it is best to look at impacts to specific regions. Many of these aspects can be modified to fit other regions and thus also have a wider applicability. Some of potential impacts are described in the following:

France

As presented in the report from the French study case, the operational implementation of the Flexwood concept could provide relevant information to professional stakeholders to improve their decision making process regarding wood allocation. The French case deliberately chose to target wood supply companies as potential users of the Flexwood. Therefore, its scope was limited to the decision making operation through which round wood demand is to be properly translated into cutting instructions to harvest the panel of available blocks.

Industrial practitioners were interviewed on whether this application of the FLEXWOOD concept could prove to be beneficial for the supply companies, in terms of Organization, Economy and Service to the client, in comparison to “business as usual”.

Qualitative evaluation of the Flexwood concept applied to harvest planning in French study case

Indicators	Inventory costs	Productivity	Time before delivery	Perfect order fulfilment	Storage rate	Produce to monetary value
BAU	Reference situation	Reference situation	Reference situation	Reference situation	Reference situation	Reference situation
FlexWood	-	+	++	++	+	+

Legend: negative impact (-); positive impact (+ or ++)

For now, this case is considered as a successful proof of concept in the context of cultivated Maritime pine in Aquitaine. Although this is not representative of the diversity of the French forest-based sector, this first application could already have an important impact. It indeed contributes to answering a major challenge faced by the forest industry in south west France: resource scarcity and fierce competition on raw material by different value chains (solidwood, pulp&paper and energy) after the last storms.

The Flexwood point of view (on who embodies a relevant user of the concept) could also be moved earlier in the supply chain: to the forest owners. These stakeholders could seek through a Flexwood-inspired system to promote their standing timber for sale in a more elaborate format. One potential advantage would be that supply companies could be more open to pay higher stumpage fee to forest owners because the precision on the product-mix from each purchased stand will be higher (reduce the financial risk for the supply companies).

However, before any of these business cases can be effectively adopted by the actors and widely spread in day to day practices, several organizational issues and technical topics should be addressed and solved:

- Training should be thought through (user guide, training session…) in order to secure the efficient integration of a potential Flexwood system in the process by smoothing its adoption by the future users ;

- Forest stakeholders need to find a way to pool collection means for LIDAR data to be available on significant scale and to be up-dated over time
  - Share costs with other non-forestry users – e.g in France, ALS is currently collected for topography purposes only and over very specific areas (flooded shores, riverbanks…);
  - Rely on service providers (Data collection + Processing + Delivery of information) with an acceptable business offer (in term of e.g. cost, precision, service time) ;

- Improving wood allocation before harvesting is only worth the effort if WSC actors manage to improve their logistics. Without reflection and collective solutions (which local stakeholders are now trying to launch), the advantage gained might not be valorized later down the chain. Furthermore, because benefits from the Flexwood concept implementation might not be equal to each stakeholders along the supply chain (specifically, the ones investing the most for the concept implementation), a fair method to share the benefits between the stakeholders must be thought out and implemented to maintain sustainable incentive to all.

- Inter-operability is a major challenge for any new system relying on ICT modules and dealing with electronic data exchange between companies. E.g. Harvesting instructions designed with a FLEXWOOD system should be compatible with onboard computers of logging machines. This brings up the importance of standardization (e.g. StandforD or Papinet) and confirms the need to connect the results of this specific research initiative done in Aquitaine with other running collective initiatives like EXPLOTIC or eMOBOIS in France.

- The concept has been implemented according to a short term perspective and issues related to longer term planning horizon must be addressed.

Finally and to look a bit further, this proof of concept is of course understood as an incentive to continue on Maritime Pine but it could also raise interest to push further towards other cultivated species like Douglas fir or Poplar.

From the research perspective, one way to strengthen the impact of the Flexwood results would be to improve the quality models in order to strengthen the data processing which relies on them. In addition to that and in an operational perspective, it would be essential to deploy the system at real operational scale to see the robustness of this automation leap in the supply chain.

Finland

The impact related to different modules of Flexwood can be summarized as follows starting from the industrial requirements. The link between research and industry is always complex and needs improvements. In the Flexwood project a thorough review and analysis was made on the industrial requirements concentrating on quality and quantity measurers, matching stakeholders requirements and synthesis on gaps and improvement needs of the wood raw material allocation and supply processes for wood industries. These analysis will benefit forestry throughout the world.

In Finland, a new airborne laser scanning based forest stand level management inventory system was launched at large scale during 2010. For example, during 2012 approximately 3,000,000 hectares were scanned and stand attributes estimated. Therefore, Finland can be considered highly advanced country in relation to the use of novel remote sensing imageries. The importance of Flexwood-project in this context lies in the very recent advances, e.g. data fusions of airborne laser scanner data and hyperspectral data. Correspondingly, the possibilities of terrestrial laser scanner in pre-harvest measurement type inventory cases may have impact on the future inventory development. Worldwide, the impact of inventory module of Flexwood varies from completely novel inventory approach to the situation like in Finland.

Correspondingly as in the case of inventory module Finland can be seen highly advanced country related to modules of harvesting and logistic concepts and mill production. Here the most potential impact of Flexwood can be seen as the chain of remote sensing based tree level information starting from inventory, through harvesting logistics and ending in saw mill production. Generally speaking, harvesting concepts which can adapt to market requests and changing environmental conditions as well as optimizing value adding production systems in the mill which can react to short term changes in market demands and customer needs have very high potential impacts in forestry.

The communication infrastructure including IT standards for the smooth, quick and safe communication of forest and different elements in the wood supply chain can be seen as a basic requirement for a modern wood supply chain. Finally, the demonstration of Flexwood concept in different use cases proved that the advanced methods of Flexwood can successfully be implemented in real life applications. The use case of Sweden can be seen as the most potential for the Finland but also the other use cases demonstrated the potential of alternative approaches than what is applied here.

End Users – Sawmills (WP6000)

The results of the FlexWood project will also impact directly on the industrial business and production environment of mills in the following ways,

- Wood conversion companies will get raw materials, volumes and qualities, they need just in time. This means considerable less waste and storage.
- The FlexWood results strongly support customer orientation and manufacturing value added products instead of low price bulk and standard products.
- Wood converting companies will get new tools for optimisation activities throughout the wood products supply chains.
- Wood companies, machine manufacturers and system suppliers will get new short and long term concepts and knowledge to allow them
    - to convert non-homogenous wood raw material to products with precise defined properties with maximum yield and minimum waste
    - to improve considerably flexibility of manufacturing systems
    - to make business and production adaptive to external changes
- Better allocation of wood raw material will lead to environmental impacts:
    - lower energy consumption, optimal (shorter) transportations of wood raw material to the mills.
    - less waste, right wood raw material to the right mill

Norway

The Norwegian parts of Flexwood projects have been related to tree species classification and calculating of the value of the forest inventory information. The research in Norway is documented in one published paper, one accepted paper, two submitted papers, and have been presented at several conferences/workshops both in Norway and internationally. Tree species information are a key forest property for the wood supply chain and the current practice in Norway and several other countries is to manually interpret aerial photographs. The Flexwood project has showed that this species information can be achieved automatically with novel technology.

The additional values and improved process efficiencies achieved by improved measurements of the standing forests, improved harvesting decisions, improved selection, bucking and sorting at harvesting, improved transport logistics and improved information, communication and decision support systems along the wood supply chain are important for Norwegian forestry. By integrating our improved measurements of standing trees with tools for planning harvesting, cutting and supplying forestry products, the Norwegian forestry companies see a great potential to improve the value and efficiency in meeting industrial requirements. Our improved inventory systems allow efficient and better understanding of the resource in terms of quantity, quality, and location and e.g. Norwegian forest inventory companies and forest owner associations are now eager to implement this in practice.

Sweden

The potential impact of the Flexwood project is great in Sweden. The possibility to acquire detailed information about wood dimensions per specie already in the forest, before the timber is cut enable the forest industry to respond faster and more accurate to a change in demand from the industry. To know where you should focus harvesting activities in order to get a result as close as possible to the customer demand will increase the value of the forest and make Swedish forestry more efficient in utilizing the resources in an effective way.

ALS/TLS (WP4000):

With hyperspectral images the classification of species was increased significantly. The better species classification, the better prognoses of output from harvesting activities. To measure each tree in the forest instead of acquiring just average information about the stand makes it possible to find the exact area to cut to fulfil the demand of the industry/market.

The use of the Flexwood concept also lead to new information of high value for the forest industry and the landowner. One example of this is digital terrain models. When LIDAR scanning of the forest is used (according to the Flexwood concept) a side product from the LIDAR –data is digital terrain models, DMT. A DMT is a 3D map of the terrain without the forest. This map can be used to identify what areas that are to wet or to steep to drive harvesting machines in. To have this information when planning harvesting activities is of great value, because this enables the forest planner to avoid areas with potential risk of damaging the soil or getting stuck with the harvesting machine. The detailed map of the terrain and the forest makes the planning of forest activities much more efficient and accurate.

In the last years FORAN have been implementing the technology described and tested in the Flexwood project. We see a huge interest and have already applied the concept on several hundred thousand hectares of forest in Sweden. The potential impact of the new technology is that it will be used in all Swedish forestry to some extent.

Wood supply chain descriptive framework (WP5100):

Investment in R&D and knowledge/technology transfer in the fields of supply chain management, logistics and value chain optimization is one major initiative to improve the competitiveness of the Swedish forest products industry. The reference model developed in WP5100 introduced a first common vocabulary to be used by researchers and practitioners of different disciplines active in these fields. Recent initiatives by the Forest Industry and Forest and Engineering Royal academies (IVA and KSLA) will be used of the work in 5100 to be able to describe and find ways to develop Forest industry Value chains.

Meeting market based quality and quantity requirements, bucking to value and novel logistic concepts (5300 – 5500):

Skogforsk and Logica will continue the work in 5500 to develop a commercial software wich will be spread widely over Swedish forestry. This will help a fast implementation of the findings in task 5300, 5400 and 5500.

Skogforsk is leading the work with the standard StanForD, standard for cut to length technique in Europe. In this work findings from task 5300 and task 5400 will be implemented.

The project as a whole, reflecting the entire wood-supply-chain

As a whole, in Sweden the FlexWood concept represents a high potential to improve the performance of a number of Swedish wood supply chains, i.e. increase revenues and decrease costs. This is possible by dispatching wood fiber meeting very precise quality specifications. This is achievable through better data acquisition, information management and logistic performance throughout the value chain.

Canada

In Canada, many components of the project are relevant to current challenges are expected to raise interest; some of these are discussed in the following:

ALS/TLS (WP4000):

Canadian forests cover large areas for which access is often difficult or limited. Although species diversity and forest stands variations would seem to justify fairly intensive sampling-based inventories forest companies limit to a minimum their forest inventory expenses. Technology that could provide cheaper access to forest composition and mensuration data generate interest. ALS is rapidly gaining in application.

TLS is not as well documented. Potential for TLS application in the short term seem more promising in stands composed of large stems and with cleared understory, such as those found in Western Canada. For Eastern Canada forests, stem modelling represents a challenge.

Wood supply chain descriptive framework (WP5100):

Investment in R&D and knowledge/technology transfer in the fields of supply chain management, logistics and value chain optimization is one major initiative to improve the competitiveness of the Canadian forest products industry and support its transition to the modern bioeconomy (see e.g. http://www.reseauvco.ca/en/home/). The reference model developed in WP5100 introduced a first common vocabulary to be used by researchers and practitioners of different disciplines (e.g. forest engineering, management sciences, industrial engineering) active in these fields. Moreover, the work conducted in WP5100 identified several areas for further development in these fields. Eleven of those are presented in WP5100's deliverable and were discussed during a joint industry-government-academic seminar in Canada. Recently, some opportunities have been integrated in the new 5-years program of FORAC Research Consortium.

Optimization model for harvesting operation scheduling (WP5500):

FPInovations is developing a decision support software suite (http://fpsuite.ca/) that includes basic scheduling algorithms. There is also a number of IT consulting companies on active on the Canadian forest products industry market. They might be interested in developing further their service offer using models developed by FlexWood. A large forest product companies that directly manage operations that include hundreds of forest machines in Eastern Canada might be interested by WP5500 results. A significant change in operations management would be required in most places to yield a more receptive test bed for scheduling algorithm applications.

Harvesting operations and customers demand integration in sawmill manufacturing process (WP6000):

Any research results on better integration and coordination of the sawmill manufacturing process with upstream and downstream processes in the forest products industry value chain is highly relevant for the Canadian industry. Any equipment supporting such improvement is also of high interest by Canadian equipment companies and research groups.

The project as a whole, reflecting the entire wood-supply-chain

In Canada, the FlexWood concept represents a high potential to improve the performance of a number of Canadian wood supply chains. Specifically, it has been demonstrated that wood quality variation has a significant impact on sector profitability. Wood supply cost reduction, while still important, is less critical to sectorial profit than increased output value and process efficiency. This is possible by dispatching wood fiber meeting very precise quality specifications. This is achievable through better data acquisition and information management throughout the value chain. Increased responsibility by government which own the largest share of forest areas might provide an opportunity.

However, there are a number of significant issues that must be addressed before implementation in the industry. First, data acquisition costs Second, data ownership. Three, this will require a data and information sharing platform. Fourth, relatively small tree in unmanaged forest make stem modelling a challenge.

Dissemination

Considering the extensive scope of the project, it is not surprising that the stakeholders are very diverse. The primary cluster of FlexWood stakeholders is logically concentrated around the wood supply chain. Work Groups within the project investigate all facets of the chain, from laser scanning technologies, to harvesting, logistics and the saw mill industry. Together, the team explores the interdependencies, overlap and connections between these units, facilitating the flow of the chain as a whole. In this sense, there are two types of results from FlexWood that are interesting for stakeholders of the wood supply chain: each partner has expertise on a certain link in the chain, so the research and products of these smaller units are of interest to stakeholders of each respective field; furthermore, the project encompasses all segments of the supply chain, thus, the resulting FlexWood system as a whole is relevant for both stakeholders that are focussed on a unit of the chain, as well as stakeholders that concern themselves with the chain in its entirety.

Institutes, businesses and organisations involved in scientific and industrial aspects of the wood supply chain were those targeted in the dissemination of the project. This mirrors the composition of the group, which includes major organisations from both the research and industry side. In terms of manufacturing processes, the project is focussed on the saw milling industry. In addition to these sectors, it is always of benefit to inform the general public of progress in research and innovation. Institutions or organisations involved in policy are, on the other hand, relevant to a much lesser extent.

Geographically, targeted stakeholders varied from a regional or national to European and world-wide level. Some results have a strong regional focus, such as the project's Use Cases, which are specific to France, Germany, Sweden and Poland (although they are representative of larger regions). Other results are interesting on a world-wide level, such as forestry laser scanning research findings, which are pertinent to a closely knit group of specialised scholars, amongst others.

The team was very active in the many means of dissemination; presentations were held for local and international groups at specific workshops and major conferences. A flyer and website communicated information and other media was used when relevant. Many stakeholders were contacted directly. The team hosted a session specifically for FlexWood at the IUFRO Div 5 conference in July 2012 and held the FlexWood Symposium final meeting in Helsinki in September 2012.

Conclusion

In summary, the overall impact of the project for wood supply chain is the enhancement of tools and procedures for information assessment and improvement of the information flow. The project developed supply chain optimisation models at both a tactical and strategic planning level, which supports decision-making towards matching the wood supply from the standing forest with competing industry requirement. The value recovery within the wood supply chain will be optimised based on these sophisticated models. The concepts within FlexWood also lead to a quicker and more flexible response to the changes in market demands and available supply. The above mentioned aspects have high potential to the socio-economic impacts and also even to wider societal implications. The still challenging aspect is to successfully disseminate these improvements to the operational Forestry.