Long-term outlook for wood construction in Europe

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Academic dissertation

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ABSTRACT

The aim of the study is to examine the factors affecting the market potential of wood construction in Europe towards 2030. The study takes three complementary perspectives: Past trends and current structures, future trends and uncertainties and measures required to meet the long-term targets of the industries.

The methodological framework builds on combining quantitative, descriptive and participative research approaches. By adopting methods and approaches from the field of foresight, the study aims to contribute also to the methodology development for long-term forest sector outlook studies.

The trends and pressures in the operating environment of construction were found to primarily relate to the need for reducing the environmental impact of construction and improving the quality and productivity of construction. However, few of the trends would appear to have decisive impact on the diffusion of wood construction. That is, the positive drivers might not translate into improved competitive advantage for wood construction to the extent often expected, due to the lack of willingness or ability to pay for the attributes exceeding the requirements posed by the building regulations. Instead, the cultural and structural hindrances culminating to the fragmented structure and risk-averse characteristics of the construction and wood products industries seem to create significant inertia for the diffusion of wood construction.

Based on scenario analysis, the outlook would appear to be dependent on the possible regulatory push for green building and on the possible changes in the strategic orientations of the industries. However, the empirical part indicated that the short-term strategy and policy measures suggested by experts are regarded either as unlikely or as unattractive by the industry stakeholders. The results therefore suggest that the diffusion of wood construction in Europe is likely to be a gradual process, subject to significant inertia, and restricted to a few niche sub-sectors and regions towards 2030.

ACKNOWLEDGEMENTS

The process of drafting the thesis has been anything but straightforward. Nonetheless, at no point do I recall nurturing second thoughts on the sense of seeing it through.

The project was conducted under the auspices of the European Forest Institute. I am urged to confirm the rumour that one year spent at the EFI equals two years of experience elsewhere. I would like to express my sincere gratitude to my supervisor Lauri Hetemäki for sharing his valuable experience and for the precise balance of encouraging independent critical thinking on one hand and challenging the disproportionate ideas on the other hand.

My special thanks are extended to the people who have made the research possible over the past four years and the research fellows I have had the chance to exchange ideas with, whether on or off the topic. In particular, I wish to acknowledge the help of various forms provided by Perttu Anttila, Gert-Jan Nabuurs, Riitta Hänninen, Päivi Pelli, Annukka Näyhä and the fifth floor staff from the University of Helsinki. It is a privilege to have had Prof. Eric Hansen and Prof. Anne Toppinen as the pre-examiners of the thesis. The proofreading by Isto Hurmekoski is very much appreciated. Moreover, I would like to offer warm thanks for all co-authors, trainees, data providers and those attending the surveys.

I would like to express my gratitude to the foundations that have financially supported the research, namely the Foundation for European Forest Research (FEFR), Metsämiesten Säätiö Foundation, the Graduate School of Forest Sciences (GSForest), the Finnish Society of Forest Science (SMS) and the Finnish Forest Foundation. Moreover, the funding by the Academy of Finland for the FORBIO project has guaranteed the continuity of the research, as well as helped and motivated in finalising the thesis.

Family members and friends deserve my unbounded gratitude for all the support and mental nourishment of various sorts. Finally, there is only one assertion in the thesis that I can stand behind without a hint of uncertainty; I am grateful for our time together, Reetta, and I look forward to our shared years to come.

In Joensuu, on the 13th of January 2016

Elias Hurmekoski

LIST OF ORIGINAL ARTICLES

This dissertation consists of four articles and a summary. Articles I, II and III are reprints of previously published articles reprinted with the kind permission of the publisher. Article IV is the authors' version of a submitted manuscript.

I   Hurmekoski, E., Hetemäki, L. (2013). Studying the future of the forest sector: Review and implications for long-term outlook studies. Forest Policy and Economics 34: 17–29.
        http://dx.doi.org/10.1016/j.forpol.2013.05.005

II   Hurmekoski, E., Hetemäki, L., Linden, M. (2015). Factors affecting sawnwood consumption in Europe. Forest Policy and Economics 50: 236-248.
        http://dx.doi.org/10.1016/j.forpol.2014.07.008

III   Hurmekoski, E., Jonsson, R., Nord, T. (2015). Context, drivers, and future potential for wood-frame multi-storey construction in Europe. Technological Forecasting and Social Change 99: 181-196.
        http://dx.doi.org/10.1016/j.techfore.2015.07.002

IV   Hurmekoski, E., Pykäläinen J., Hetemäki, L. (2015). Assessing long-term targets for green building – The case of Finnish wood-frame multi-story construction. Manuscript.

Author's contributions in co-authored articles

	I	II	III	IV
Conception and design	LH	EH	EH	EH
Planning	EH, LH	EH, LH, ML	EH	EH, JP
Data collection	EH, LH	EH	EH	EH
Data analysis	EH, LH	EH, ML	EH, RJ	EH
Writing the article	EH, LH	EH	EH	EH
Editing and reviewing the article	EH, LH	EH, LH	EH, RJ, TN	EH, LH, JP
Overall responsibility	EH	EH	EH	EH

EH = Elias Hurmekoski, LH = Lauri Hetemäki, ML = Mika Linden, RJ = Ragnar Jonsson, TN = Tomas Nord, JP = Jouni Pykäläinen

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1 INTRODUCTION

1.1 Wood products markets

The wood products industry consists of three main sub-sectors: Sawnwood, wood-based panels and secondary processed products (NACE Rev. 2 class C16). The largest sub-sector by volume is sawnwood, with the production of 102.9 million m^3 in the EU in 2014 (FAOStat 2015). In contrast, most of the value added is generated in the secondary processed products industry (Sandberg et al. 2014), consisting of joinery and carpentry, wood-based composite and engineered wood product (EWP) sub-sectors.

The EWP markets have expanded rapidly in Europe in the 2000s (Pahkasalo et al. 2014). Some of the most common EWPs include glued laminated timber (glulam), laminated veneer lumber (LVL), I-joists, and cross laminated timber (CLT, KLH, X-lam, etc.). In each of the EWPs, layers of wood, either sawn or peeled, are glued together to improve the dimensional stability and mechanical performance of the product compared to solid wood. The term 'engineered' refers to manufacturing the wood-based products to withstand a given level of stress and to meet building regulations (Karacabeyli and Douglas 2013). That is, the EWPs compete primarily with steel, concrete and other large scale construction systems, where the use of wood has remained low in Europe on average.

Around 70 % of the end uses of wood products are related to construction (Hänninen et al. 2007), including structural and non-structural frames, scaffolding, interior and outdoor products, window frames and doors, floors, roof trusses and facades (Sandberg et al. 2014). The other major uses include the manufacture of furniture and packaging materials.

As the construction sector largely profiles the demand for sawnwood, the demand shifters are generally linked to factors of economic activity such as income, interest rates, and consumer confidence, and demographic factors such as net household formations, net birth rate, and immigration (Baudin 2003; Schuler and Adair 2003). Since the major demographic and economic indicators do not seem to support strong growth for housing demand in Europe towards 2030 (OECD 2012; UN 2015a, 2015b), the increase in the use of wood in the long-run seems possible mainly through changes in the level of consumption per capita (CPC).

While the aggregate level statistics for the European Union show no significant changes in the sawnwood CPC over the past decades, some data do reveal major changes in single countries. Most notably, in Finland the sawnwood CPC approximately doubled over the period of 1995 to 2000 (see Fig. 1). Some of the suggested drivers for the increase include public wood promotion campaigns and technology platforms, successful examples and removing institutional obstacles (Hetemäki et al. 2011).

The empirical research on the European wood products market developments in the 2000s has focused on methodology development for estimating price and income elasticities to serve demand and trade projections and forecasts (e.g., Simangunsong and Buongiorno 2001; Jonsson 2013), while studies analysing the market structures have
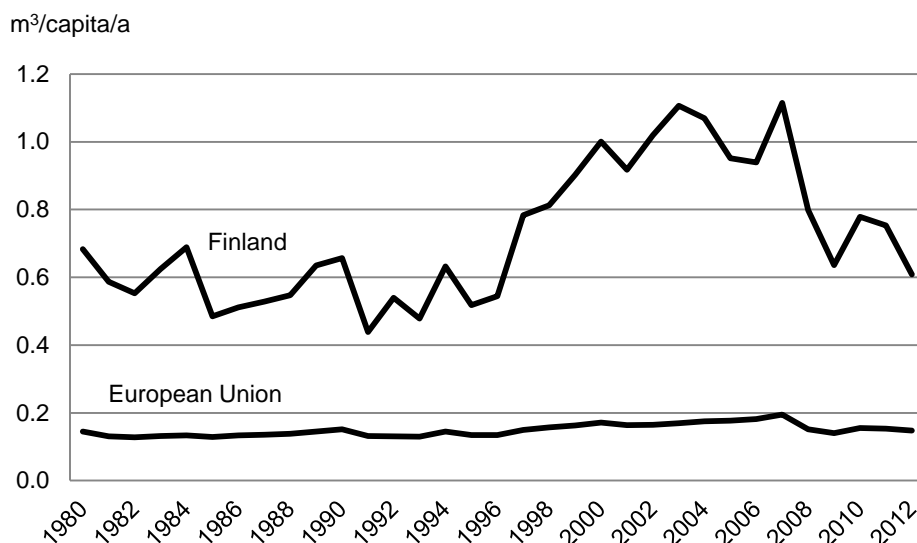
m³/capita/a

Figure 1. Sawnwood consumption per capita in the EU and in Finland (FAOStat 2015).

remained relatively scarce (e.g., Mutanen and Toppinen 2005; Lundmark 2007). A number of qualitative expert analyses and reports discuss the possible drivers of sawnwood consumption, related to demographics, culture and traditions, consumer preferences, environmental issues and policy push and pull (e.g., Hetemäki et al. 2011; Enroth and Valtonen 2012). However, studies attempting to quantify and validate the assumed linkages between the possible drivers and sawnwood consumption seem to be scarce and studies focusing specifically on the sawnwood CPC would appear to be missing. Consequently, the assumptions on the factors affecting sawnwood consumption in Europe have remained to some extent hypothetical.

1.2 Wood construction

Wood construction refers to any form of construction in which the load-bearing structural frame is made of wood-based products. Wood has traditionally been used mainly in single-family buildings. However, with the emergence of EWPs, wood has increasingly been used also in large scale construction, such as bridges, industrial halls, sport centres and multi-storey residential buildings (Bühlmann and Schuler 2013; Pahkasalo et al. 2014).

The market share of wood construction in the detached house construction markets has remained at around 8–10 % in Europe on average over the past decades (Alderman 2013). However, it varies regionally, from above 80 % in the Nordic countries to near zero in a number of Southern European countries. In the multi-family residential construction markets, Sathre and Gustavsson (2009) assume the market share of wood to be 5 % on

average, most of which in buildings with two storeys or less. The lack of consistent data on the use of wood in multi-storey buildings indicates that the market share in the segment of three storeys and more is likely to be below 1 % on average, even though also in these markets there are significant regional differences (Jonsson 2009). Even less data exist on the renovation and infill construction markets, even though the market potential for wood in these segments has been noted to be significant (Kristof et al. 2008).

The thesis focuses on the wood-frame multi-storey construction (WMC) markets in particular, owing to the recent major changes in these markets and the high potential of WMC for contributing to green building (see Wang et al. 2014). WMC was prohibited by building regulations in most European countries until the late 1980s, due to the negative perceptions arising from historic city fires (Mahapatra and Gustavsson 2008). Following the adoption of functional building regulations in the EU and the technological advances in engineered wood products and in construction elements based on them, the market share of WMC has begun to increase in the 2000s in the Nordic countries, the Alpine region, and the British Isles. Particularly in Finland the market share of WMC has grown exponentially, from 1 % in 2011 to nearly 10 % in 2015 (TEM 2015), hence practically meeting the target set by a government program in 2011 (Finnish Government 2011). Nonetheless, the diffusion has had very limited impact on the overall housing stock, in that by the end of 2014, only around 1,500 apartments were in a wood-frame building out of the total of 1,269,000 apartments in multi-storey buildings in Finland (Tolppanen 2015). In most parts of Europe, WMC practices are completely unknown, with the exception of a few pilot projects.

The concept of green building refers to the need for addressing the environmental, social and economic issues of construction, by emphasising life-cycle perspective, environmental sustainability, health issues and impacts on the community (Zuo and Zhao 2014). The potential of wood construction for addressing the socio-economic issues of construction builds on the concept of industrial prefabrication, which refers to a shift from on-site construction to manufacturing of elements and components off-site, i.e., combining several work phases in a single off-site location (Malmgren 2014). The potential benefits compared to traditional on-site construction include efficient moisture, quality and cost control, improved worker safety, and most importantly, efficiency gains due to optimised assembly and the simple and quick erection phase (Brege et al. 2014).

A significant body of literature recognises the possible environmental benefits of substituting the most common building materials for wood-based products (e.g., Ruuska and Häkkinen 2012, 2014; Pajchrowski et al. 2014), especially in terms of the amount of energy needed for producing the building products (embodied energy) and the resulting CO_2 emissions (embodied carbon). That is, wood-based products can contribute to climate change mitigation by sequestering CO_2 in standing forests and storing carbon in wood-based products and by substituting wood for steel, concrete, and other products that use more energy in their manufacture, hence avoiding larger fossil fuel consumption and consequent CO_2 emissions (Sathre and Gustavsson 2009). According to a number of meta-analyses (Sathre and Gustavsson 2009; Sathre and O'Connor 2010; Ritter et al. 2011;

Oliver et al. 2014), the studies invariably conclude that wood-based construction practices cause less environmental burden, although depending on the assumptions, the difference in terms of CO_2 emissions can be rather small towards the end of the life cycle. Also, it needs to be noted that these studies typically compare wood to ordinary Portland cement and do not therefore consider the possible improvements in the environmental performance of the most common building materials (see e.g., Hasanbeigi et al. 2012).

The ability to pursue green building is countered by the structural inertia and path dependencies of the construction sector (Mahapatra and Gustavsson 2008). The construction industry is generally considered more risk-averse, fragmented, and path dependent than most other sectors of economy (Arora et al. 2014). That is, accustomed building practices are favoured over alternatives due to existing norms and institutions, investments in the existing infrastructure, expertise, capital intensive machinery and the large number of loosely coupled small actors in the construction value chain (Mahapatra and Gustavsson 2008). The established, path dependent innovation systems based on cost competition do not encourage other than incremental innovation and easily make the actors unwilling to accept new practices which potentially cause extra work and associated costs in the short-run (Arora et al. 2014). Partly for these reasons, the commercialisation of new products, processes, or business models in this sector typically takes several decades. However, referring to the policy agendas (EC 2010, 2011, 2012, 2014) and industry positioning papers (ECTP 2005; FTP 2012) that strongly advocate green building, it is critical to note that the market structures do not inevitably remain unchanged in time.

It would appear that there is a major research gap on future-oriented wood construction market analysis in Europe. That is, studies analysing the wood construction markets seem to be clearly outnumbered by the literature on the technical and regulatory aspects of wood construction (e.g., Smith and Frangi 2008; Östman and Källsner 2011) and on the perceptions towards wood construction (e.g., Roos et al. 2010; Wang et al. 2014). While a number of market and strategy analyses on wood construction in Europe can be found (e.g., Lattke and Lehmann 2007; Junnonen et al. 2011), studies focusing explicitly on the future market potential of wood construction seem scarce and mostly restricted to reports not subject to peer-review (e.g., CEI-Bois 2004; Jonsson 2009).

1.3 Outlook studies and foresight

According to Bell (2003), the purpose of future-oriented research, typically termed futures studies or foresight, is to discover, examine and evaluate possible, probable and preferable futures. Glenn (2009) summarises five philosophical assumptions that motivate future-oriented research: (i) The future cannot be known, but a range of possible futures can be known, (ii) the likelihood of a future event or condition can be changed by policy, and policy consequences can be forecasted, (iii) gradations of foreknowledge and probabilities can be made, (iv) a collection of methods yields more reliable results than any single method, and (v) humans will have more influence on the future than they did in the past.

The value of future-oriented research is less in forecasting accuracy. Instead, it aims to improve the understanding of the present, challenge fixed thinking, make the organisation or individual more effective in dealing with change, illuminate policy choices and identify and evaluate alternative actions.

Outlook studies have long traditions in the forest sector – they extend back to the 1950s. According to UNECE/FAO (2011a), forest sector outlook studies (FSOS) examine long-term economic, social, institutional and technological trends to support policy reviews and strategic planning, depicting the range of choices available and describing the alternative scenarios that might arise as a result of these choices. The practical focus and implications of the FSOS have been on forest products consumption, production and trade flows, and the availability of wood resources.

The most recent and influential European forest sector outlook studies (Mantau et al. 2010; UNECE/FAO 2011a) suggest – irrespective of the scenario – that the forest product markets will keep growing at a steady pace of less than one percent a year. There are only few exceptions, such as the bioenergy and wood-based panel markets that are projected to grow more rapidly. Correspondingly, the demand for wood resources in Europe is expected to keep increasing. However, the mainstream forest sector outlook studies have not fully considered the possible effects of a number of the ongoing and forthcoming structural changes, such as the decline in demand for many communication paper grades (see Hetemäki 2014). Indeed, the most recent outlook studies projecting the demand for wood products were outdated already by the time of publishing (e.g., Buongiorno et al. 2012), due to the rapidly changing global competitive advantages and the impact of the global financial crisis from 2008 onwards. Given more recent data, the forthcoming outlook studies can provide updates to the projections in terms of the economic downturn, yet these updates cannot negotiate the more critical issue of structural change.

A number of the issues with long-term projections based on modelling approaches have been commonly acknowledged (Buongiorno et al. 2012), although not fully considered or studied in detail. As only few recent outlook studies have attempted to take a step towards complementary approaches other than quantitative modelling (UNECE/FAO 2011a; Wear and Greis 2011), there appears to be a need for exploring complementary research approaches more systematically (see also Toppinen and Kuuluvainen 2010). One useful orientation to be explored is the foresight and futures studies literature (see Bell 2003; Glenn 2009).

As noted by Pelli and den Herder (2013), foresight thinking has been present in a number of high-level decision-making processes in the forest sector, for example in vision building and goal setting (bioeconomy strategies), strategy formulation (the foresight work of private enterprises), technology platforms (the Forest-based Sector Technology Platform), and policy-making (Forest Europe and EU Forestry Strategy processes). However, in the forest sector outlook studies or academic forest sector journals, references to the academic foresight journals or to the authoritative textbooks such as van der Heijden (1996) or Bell (2003) have remained scarce, with few exceptions (e.g., Navarro et al. 2008; Pelli 2008; Jonsson 2011). Also, foresight entails an inherently normative nature, which has

been to a large extent ignored in the forest sector. Hence, the thesis aims to explore the possibility of adopting tools and approaches from the field of foresight to complement the forest economics orientation in forest sector outlook studies.

1.4 Objectives and scope

The overall aim of this study is to examine the factors affecting the market potential of wood construction in Europe. While the study aims to contribute to the forest economics and sectoral analysis literature by discussing the validity of the methodological approaches for long-term outlook studies, it has also a more pragmatic objective of providing information for strategic decision-making in the private and public sectors. The specific research problems are:

I.   How could the methodological approaches of forest sector outlook studies be modified to improve upon their relevance for decision-making? Does the foresight literature from other sectors provide valuable insights?
II. What determines the level and growth rate of sawnwood consumption per capita? What do the current market structures and past trends imply for the future market potential of wood construction?
III. Which trends and uncertainties in the operating environment seem to be decisive for the future market potential of wood construction in Europe?
IV. What is the nature of changes in the strategy orientations and in the regulatory environment that would allow meeting the industries' long-term targets?

The study aims to generalise the main findings across Europe. However, due to the vast differences in the contexts and drivers of wood construction between regions, some of the sub-studies focus mostly on the Nordic countries, taking the case of Finnish WMC markets in particular. The temporal scope of the analysis extends from 1980 to 2030. The outlook of around fifteen years is long enough to allow the possibility of structural changes yet brief enough to remain tangible for the stakeholders.

2 METHODS AND DATA

2.1 Background and conceptual framework

Paper I carried out a critical review of long-term forest sector outlook studies. The review covered studies with an outlook for over a decade and with a primary focus on the forest products markets and demand patterns. While the review does not claim to be exhaustive, it is seen to cover the mainstream of the forest sector outlook studies published in English

between 1995 and 2012, focusing on forest products markets. Of the non-journal publications, only the most recent ones were included. The data were gathered mostly from the Science Direct database (journal articles) and Google Scholar (other types of publications), using search terms related to outlook studies and future prospects of the forest sector. The sample covered 25 evidence-based outlook studies (e.g., Turner et al. 2005; Mantau et al. 2010; Raunikar et al. 2010; Kangas et al. 2011; UNECE/FAO 2011a; Wear and Greis 2011; Buongiorno et al. 2012) and 11 qualitative outlook studies (e.g., Navarro et al. 2008; Jonsson 2011; UNECE/FAO 2011b; FTP 2012). In addition, the paper reviewed the general foresight literature (e.g., Bell 2003, Glenn 2009) and applications from the energy sector (e.g., Vergragt and Quist 2011) to yield suggestions on how to improve the informational value of forest sector outlook studies.

As noted in Paper I, future-oriented market analysis is bound to follow inductive reasoning, as controlled experiments on the future cannot be carried out. Also, the global economy forms such a complex system that considering the combined impact of the affecting factors and measuring and reliably projecting their impact remains beyond human or artificial cognition capacity (Makridakis et al. 2009). Due to these fundamental constraints, the thesis combines quantitative, participative and descriptive approaches and emphasises the triangulation of methods, data and theories (see e.g., Näyhä 2012). This allows studying the topic from as versatile perspectives as possible, thereby increasing the validity and usefulness of the results.

The review contributed to formulating the conceptual framework of the thesis, which builds on the three cornerstones of futures studies, i.e., probable, possible and preferable futures (see Bell 2003). As shown in Figure 2, each of these perspectives was applied for the case of wood construction and wood products markets: Paper II analysed the past trends and the current structure of the markets to derive probable future directions, Paper III explored alternative future directions by identifying a set of critical uncertainties affecting the outlook and Paper IV discussed the possible measures to meet normative long-term targets set by the industries.

2.2 Econometrics and data analysis

Econometrics refers to the art and science of measuring economic relations (Chow 1983). It can be used for formally estimating and understanding economic relationships, testing economic theories and evaluating policies (Wooldridge 2000). Paper II applied econometric analysis for the purpose of defining the factors affecting the level and growth rate of sawnwood consumption per capita (CPC) in Europe, i.e., understanding the structure of the markets. As the conventional forest product demand equation based on price and income appeared insufficient for this purpose, an additional ad hoc model was formulated, with the purpose of validating expert analyses on the possible factors affecting the CPC. The previous literature used for determining the hypotheses on the possible factors affecting the CPC included both empirical analyses and expert analyses, with a total of 30 publications

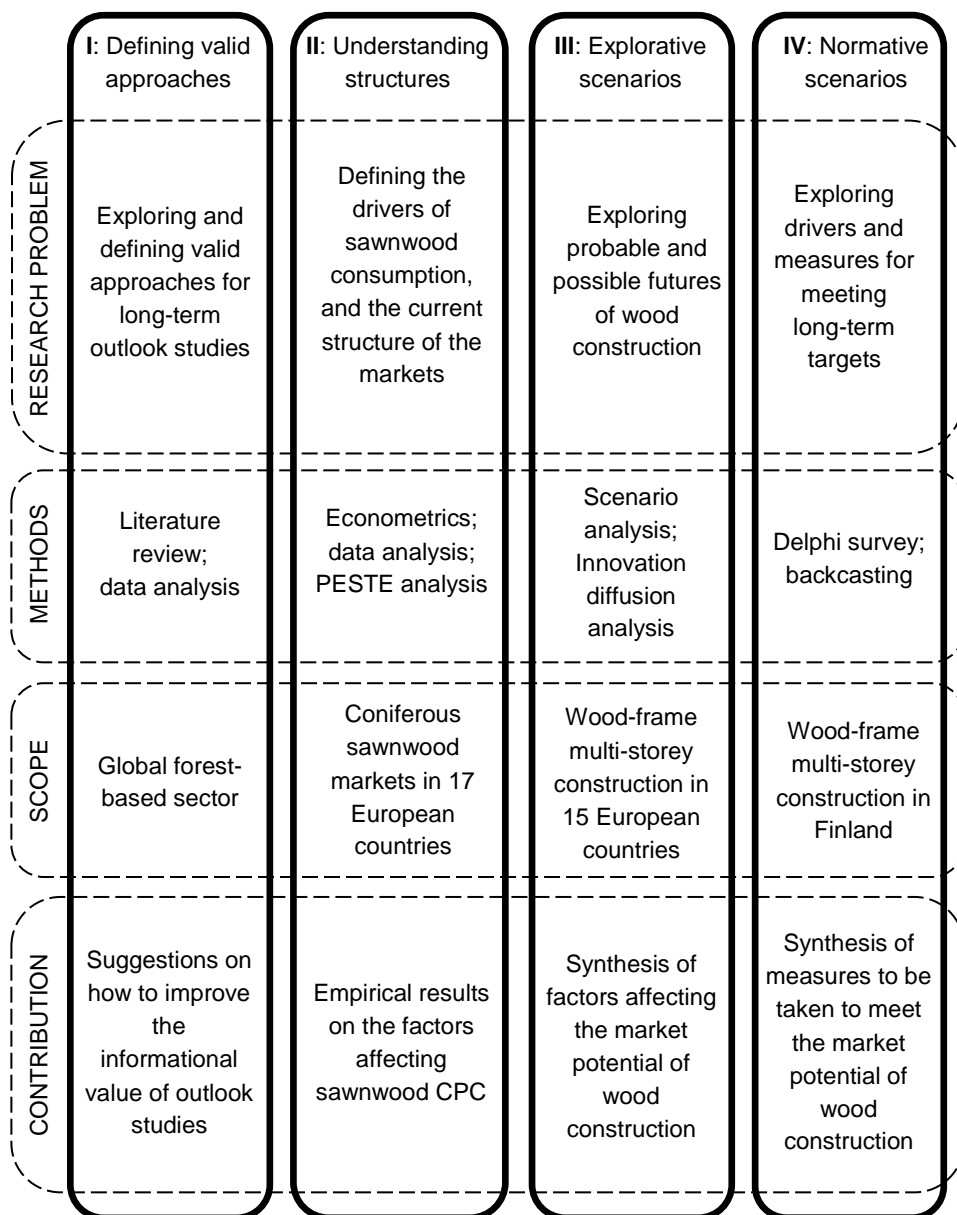| **I**: Defining valid approaches	**II**: Understanding structures	**III**: Explorative scenarios	**IV**: Normative scenarios
RESEARCH PROBLEM Exploring and defining valid approaches for long-term outlook studies	Defining the drivers of sawnwood consumption, and the current structure of the markets	Exploring probable and possible futures of wood construction	Exploring drivers and measures for meeting long-term targets
METHODS Literature review; data analysis	Econometrics; data analysis; PESTE analysis	Scenario analysis; Innovation diffusion analysis	Delphi survey; backcasting
SCOPE Global forest-based sector	Coniferous sawnwood markets in 17 European countries	Wood-frame multi-storey construction in 15 European countries	Wood-frame multi-storey construction in Finland
CONTRIBUTION Suggestions on how to improve the informational value of outlook studies	Empirical results on the factors affecting sawnwood CPC	Synthesis of factors affecting the market potential of wood construction	Synthesis of measures to be taken to meet the market potential of wood construction

Figure 2. The framework of the thesis.

(e.g., Eastin et al. 2001; Baudin 2003; CEI-Bois 2004; Kärkkäinen 2005; Kristof et al. 2008; Buongiorno 2009; Hetemäki and Hänninen 2009; Hetemäki et al. 2011; Enroth and Valtonen 2012).

Eq. (1) shows the specification of the models used

$$\ln CPC_{i,t} = \beta_0 + \alpha_i + \lambda_t + \boldsymbol{\beta}'\mathbf{X}_{i,t} + \delta \ln CPC_{i,t-1} + \varepsilon_{i,t} \tag{1}$$

where β_0 is a constant, α_i ($x_{it} = x_i$ for all t) and λ_t ($x_{it} = x_t$ for all i) are cross section and period fixed effects, respectively, $\mathbf{X}$ is a vector of explanatory variables (sawnwood price, wood-based panels price, Portland cement price, GDP per capita, renovation activity, residential construction activity, unemployment, economic openness), $\boldsymbol{\beta}$ is a vector of the coefficients for the respective variables, CPC_{t-1} is a one year lag of the dependent variable, δ is the coefficient for the lagged dependent variable, and ε is the error term.

The parameter values were estimated using two-stage least squares (TSLS), because the prices and quantities were found to be simultaneously determined, hence producing inconsistent OLS estimates. TSLS is a special case of instrumental variables regression, conducted in two distinct stages (Wooldridge 2000). While the TSLS estimates are consistent, they are only asymptotically valid, which increases the possibility of bias in small samples. Also, the tests suggested using a two-way LSDV model specification, which cannot be generalised beyond the sample studied (Baltagi 1995). The estimations were carried out with EViews 8 software (IHS 2013).

The estimation used panel data, since panel data contain information of both the differences between individual countries and the differences over time within individual countries. Also, using panel data improves the estimation efficiency and allows considering country-specific unobserved effects (Baltagi 1995). All data were converted into natural logarithms, in order to normalise the data and to be able to interpret the coefficients directly as elasticities.

The sample covered annual unbalanced panel data for 17 European countries for the period of 1980-2012, collected from FAOStat, World Bank, UN, OECD, Euroconstruct, and Statistics Finland, among various other similar sources. Appendix I summarises the variables used for the econometric analysis.

Further data analysis was conducted by calculating statistics, making visualisations (charts, cross-plots, etc.) and dividing the sample into groups. The grouping was performed using K-means cluster analysis and discriminant analysis (see Kaufman and Rousseeuw 2009). Figure 3 summarises the process of empirically validating the factors affecting the sawnwood CPC.

Finally, although not explicitly reported, a simple spreadsheet model was used to iterate the approximate implications of various levels of WMC diffusion on the wood resource demand and on the embodied carbon reduction potential in multi-storey buildings (Paper III). The main assumptions for the calculations included the construction activity, the size of apartments, the wood use intensity of the structural techniques and the production efficiency of wood products. The data sources included databases such as Euroconstruct and a variety of publications around the topic such as UNECE/FAO (2010). Appendix II summarises the main assumptions and parameter values used for quantifying the WMC
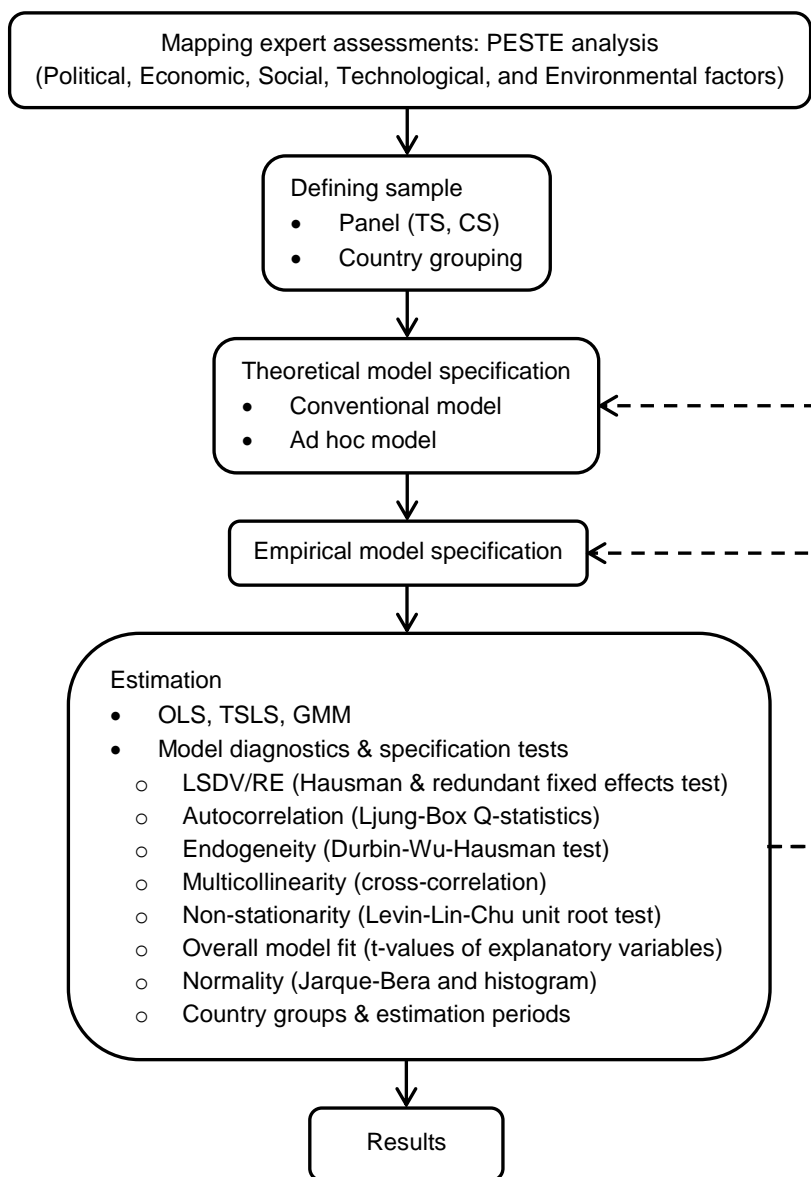
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│  (Political, Economic, Social, Technological, and Environmental factors)  │
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│      ○  Overall model fit (t-values of explanatory variables) │
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Figure 3. The process of empirically validating the factors affecting sawnwood CPC.

diffusion implications. The calculations were carried out for a sample consisting of the 15 largest countries in Europe in terms of the number of apartments built annually (AT, CH, CZ, DE, ES, FI, FR, GB, HU, IE, IT, NL, NO, PL, SE).

2.3 Descriptive and participative methods

One major aim of the study was to explore the factors that differentiate the technical potential from the socio-economic market potential of wood construction. Since long-term projections partly based on hypothetical data were not seen to satisfactorily serve this end, Papers III and IV instead followed a number of descriptive and participative research approaches to facilitate the iteration of the possible scales of the diffusion of wood construction in a qualitative scenario framework. The qualitative approaches for assessing the market potential included innovation diffusion analysis (Rogers 2003), participative backcasting (Dreborg 1996) and Delphi (Linstone and Turoff 2002).

The theory of innovation diffusion rests on explaining and forecasting the dynamics and temporal scope of a product lifecycle, which typically follows an S-shaped trajectory (Stoneman 1985; Gordon 2009). However, the market potential is a sum of a variety of complex and interrelated factors related to the attributes of the product, the perceptions towards the product and the context structure (Roos et al. 2014), which simple logistic functions tracing the S-curve are unable to capture. Accordingly, the study took a descriptive approach to explore the following issues: Who are the key stakeholders taking the decisions in the sector? What are the drivers and barriers in the operational environment affecting the market potential? Which measures could be taken to meet the market potential? How does the product compare to competing products, and how are the attributes of the product perceived by the potential adopters? Is the diffusion potential similar across countries and sub-sectors? What are the possible consequences of the diffusion?

Apart from the last question that was approached with a simple spreadsheet model, Paper III addressed the above questions by relying on secondary sources. The sample of literature consisted of a total of 65 publications: 9 publications on the operating environment of the construction sector (e.g., Schuler and Adair 2003; Kubik 2012; EC 2014; IPCC 2014); 26 publications on the outlook for the construction sector (e.g., European Foundation for… 2005; Goodier et al. 2008; Danish Technological Institute 2009; Wegner and Jones 2009; Hasanbeigi et al. 2012; Hanus and Harris 2013; Pacheco-Torgal and Labrincha 2013; Vokes and Brennan 2013; Arora et al. 2014); 19 publications on the attributes of WMC (e.g., Smith and Frangi 2008; SP Wood Technology 2009; Van de Kuilen et al. 2011; Karacabeyli and Douglas 2013; Brege et al. 2014; Muilu-Mäkelä et al. 2014); and 11 publications on the perceptions towards WMC (e.g., Karjalainen 2002; Schauerte 2010; Hemström et al. 2011; Mahapatra et al. 2012). In addition to peer-reviewed journal articles, the source material included institutional summary reports, working papers, agenda papers, industry positioning papers, conference proceedings and seminar presentations.

Backcasting is a normative scenario approach for studying preferable futures (Dreborg 1996). The backcasting approach entails looking back from a preferred future typically set by stakeholders and identifying the steps that need to be taken in order to achieve it, or alternatively, determine actions to avoid an undesired future (Quist 2007). In the thesis, the

backcasting approach provided a useful complementary analytical framework for determining the long-term targets and the point of view for the analysis in Paper IV.

The backcasting approach does not prescribe the use of any specific method (Dreborg 1996). Therefore, Paper IV used empirical data collected with a Delphi survey, employing a web-based questionnaire and semi-structured interviews, which utilised the system transition roadmap introduced by Auvinen et al. (2015). The general aim of the Delphi is to obtain the expertise, opinions and arguments of a specific group (van de Linde and van der Duin 2011). The distinction to a typical survey is that in a Delphi the survey participants are acknowledged experts of their respective fields and they remain anonymous in order to allow argumentation beyond the roles of the panellists (Linstone and Turoff 2002). A Delphi survey also consists of a minimum of two rounds, in order to iterate the survey outcomes towards desired avenues (ibid.), based on the results of the previous rounds that are made available for the participants, which gives a possibility to amend the statements.

The survey was targeted at experts and stakeholders across the wood construction value chain, mostly from Finland, but also from the other Nordic countries and Central Europe, including civil servants, interest groups, industry representatives (developers, construction companies, and material suppliers), non-governmental organisations, and researchers. The questionnaire yielded 25 responses from seven European countries, translating to a typically moderate response rate of 25 %. A total of 19 interviews were carried out, mostly with Finnish stakeholders, with the length of the interviews ranging from 45 minutes to two hours. The questions for the half-open interviews are shown in Appendix III. The responses to the open questions of the questionnaire and the transcribed interview notes were coded, with the aim to facilitate the analysis by condensing the data into more manageable units. The analysis applied four specific forms of coding, i.e., structural coding, in-vivo coding, pattern coding and axial coding (see Saldaña 2012). The coding was carried out with MaxQDA 11 software (VERBI 2015).

Together these descriptive approaches cover both top-down and bottom-up factors affecting the market potential of wood construction in Europe. These approaches relate to the concepts of market pull and technology push, respectively. That is, each of the frameworks aims – to a varying extent and with varying emphases – at considering the possible future developments in the operational environment and their possible impacts on the studied system (market pull factors), as well as the attributes of the studied technology or business model and the role that various actors play in it (technology push factors).

2.4 Scenario analysis

Scenario analysis strives to systematically explore, create, and test consistent alternative states of the future operational environment (Amer et al. 2013; Varho and Tapio 2013). By means of forcing to consider possible structural changes, scenarios create a strong link to strategies through systematic management of uncertainty (Wang and Lan 2007). It is not the purpose of scenarios to generate accurate predictions or forecasts (Van der Heijden

1996). Instead, they facilitate perceiving possible future developments over selected key dimensions (Raskin and Kemp-Benedict 2004, Postma and Liebl 2005).

Alternative means exist for classifying scenario approaches. According to Lindgren and Bandhold (2009), there are three major types of scenarios, namely trend-based (projections), contrasted, and normative scenarios. The trend-based and contrasted scenarios are explorative in nature, whereas the normative scenarios are goal oriented and aim to achieve a desired target (Amer et al. 2013). The trend based scenarios extrapolate past trends into the future, possibly by altering the values of selected drivers. Instead, the contrasted scenarios depict the future state of selected variables as a snapshot of a selected point in time. While the forest sector outlook studies typically take the trend-based scenario approach (UNECE/FAO 2011a), the thesis utilises the contrasted and normative scenario approaches.

There are several quality criteria for scenarios, including credibility, plausibility, internal consistency, transparency, and comprehensibility (e.g., Wallin et al. 2014). Most importantly, a scenario analysis needs to be useful for strategy and policy orientation.

According to Schoemaker (1995), the scenario process should include the following steps: Defining the scope and research problem; identifying key trends, critical uncertainties (CUs), and weak signals; producing the scenarios based on the identified drivers; and assessing the scenario implications. Distinguishing the key trends and CUs from the less crucial variables is essential (Schoemaker 1995). While trends refer to factors that are known to have a high impact with a high probability, CUs are variables that are known to have a major impact on the studied system, yet whose future direction is very uncertain. The careful selection of the CUs facilitates meeting the fundamental requirement of scenario analysis of each scenario being equally probable.

A number of desktop methods were used to facilitate identifying, categorising, and analysing the data for scenario analysis. The factors in the operational environment were identified using a PESTE framework, in which the drivers identified from literature were categorised into political, economic, social, technological, and environmental variables to ensure an extensive enough perspective (Johnson et al. 2008). A further classification by OECD (2005) was used to categorise innovations into products, processes, organisation, and marketing. Subsequent to identifying the relevant drivers, they were prioritised in terms of their significance for the future market potential of wood construction using a Wilson matrix, i.e., a table with two axes, namely the level of impact and the level of uncertainty (Dermawan et al. 2013; Herry et al. 2014). Once the CUs were identified, morphological analysis was used to scope out their possible future directions, along with their impacts on the WMC market potential (see Amer et al. 2013). That is, after determining alternative future directions for the CUs, a number of alternative scenarios were formulated by alternative combinations of the directions that the CUs could take. Finally, of all the identified CUs, two most relevant ones were chosen to form a 2×2 matrix to provide the basis for four alternative scenarios (cf. Jonsson 2011, Pratt 2008). The resulting four scenarios, each of which implying a different market potential for wood construction, were based on assuming two alternative future directions for both of the two CUs. The results

from each phase of applying these desktop tools are not explicitly reported, as their purpose was only to facilitate choosing the most relevant variables for the scenario analysis and to verify the internal logic of the scenarios.

3 RESULTS

3.1 Review of forest sector outlook study methodology

Paper I critically reviewed the mainstream and state-of-the-art long-term forest sector outlook studies that focus on the demand patterns of forest products. The mainstream outlook studies were found to build on evidence-based approaches, primarily on global or regional partial equilibrium market models, such as the EFI-GTM (see Kallio et al. 2004) applied in the EFSOS II study (see UNECE/FAO 2011a). The strength of the models is in simplifying and providing a systematic and theoretically founded description of the global forest products and roundwood consumption, production, prices, and capacity development and trade. That is, they help to abstract the complex setting and the operating environment of the forest sector to a few essential economic relationships.

The review indicated that the methodology of forest sector outlook studies has remained relatively unchanged over the past decades, mirroring the stable, trend-like growth in demand for the major forest product groups. Accordingly, the projections based on the modelling framework have historically been reasonably accurate, at least at the aggregate level, following the stable growth in the major forest products markets since the 1960s.

Yet one could argue that the conventional demand equation used for long-term projections is overly reduced, in that it is based on two independent variables exclusively, i.e., income (approximated by the GDP) and forest products prices. Indeed, in the 2000s, the modelling framework has struggled to capture some of the major changes in the forest products markets, most importantly the stagnating or declining consumption of a number of graphic paper grades in the OECD countries, caused by changes in the media consumption patterns. At the same time the demand for, among others, wood-based panels and bioenergy have been growing significantly and in some cases exponentially. The changes of this character have not been satisfactorily captured by the models used in the mainstream outlook studies, nor could they be captured or projected by the models applied in this study for analysing the market structures (cf. section 2.2).

The main restriction of the evidence-based approach is that it typically does not account for such emerging features that are not visible in past data. In particular, the conventional demand model faces the issue of structural changes, which refer to long-term changes in the income elasticity, as a consequence of omitting the effects of certain critical variables. Specifically, the variables depicting economic activity cannot directly capture the possible substitution effects, i.e., changes in market shares, which may lead to large projection errors

in the long-term. Yet very few of the long-term outlook studies in the review sample have attempted to develop new equations that would be capable of explaining the recent changes.

The evidence-based approach also cannot be applied for analysing markets for which there is little or no data such as high value added goods and services with relatively insignificant market volume or goods and services that are yet to be introduced to the markets. That is, the evidence-based approach is generally valid only for analysing the major, established forest products markets with a relatively stable outlook. Yet information specifically on the possible deviations from the prevailing trends ought to be of utmost interest for stakeholders.

In order to negotiate the issues with the evidence-based outlook approaches, the review explored the validity and possible value of adopting methods and approaches from the field of foresight. To better understand the potential value of adopting foresight approaches to forest sector outlook studies, one needs to accept the fundamental dilemma related to all future-oriented research. That is, how can the future be studied, if it does not exist? As no method can yield fully reliable information of the future, the value of any assessment of the future has to be judged through its usefulness in informing and facilitating decision-making. However, it needs to be noted that even though the validity of methods can be roughly evaluated in terms of their ability to serve the research questions, specific guidelines for the selection of methods are bound to remain elusive.

Fig. 4 shows a typical foresight process, covering probable, possible and preferable futures. According to the review, each of the three aspects could be elaborated in forthcoming forest sector outlook studies. That is, in mapping the current state, the studies typically examine short-term indicators that do not consider structural changes or substitution. This is mirrored to the alternative scenarios, in that the scenarios typically consider policy-driven structural changes exclusively, while not considering the more gradual, market-driven ones. Moreover, the normative aspects have been lacking almost completely, unlike for example in the energy sector, where there is an obvious need for solving long-term issues with the dependence on fossil fuels.

he review concludes that while the evidence-based quantitative models continue to be crucial elements of forest sector outlook studies in projecting likely developments of the major and established large volume forest products markets, they are evermore less likely to alone meet the information needs of the policy makers and stakeholders in the increasingly complex forest-based sector. New approaches for bridging the gap between forest sector outlook studies and foresight approaches are needed, for example in the context of analysing the means of achieving the ambitious targets for the value added and market share set by the industries (cf. FTP 2012) that would require at least to some extent decoupling from the current dominant structures.
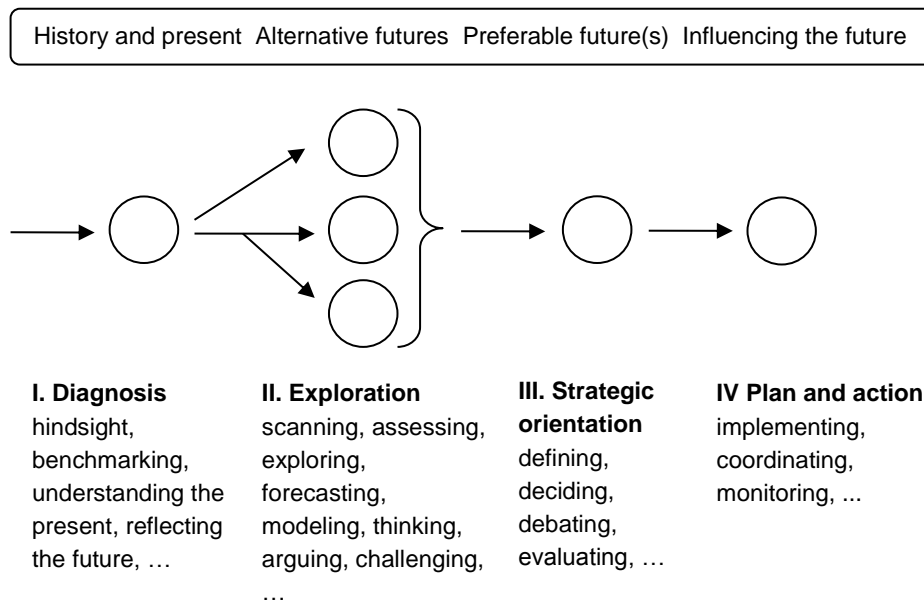
History and present Alternative futures Preferable future(s) Influencing the future

I. Diagnosis
hindsight,
benchmarking,
understanding the
present, reflecting
the future, …

II. Exploration
scanning, assessing,
exploring,
forecasting,
modeling, thinking,
arguing, challenging,
…

**III. Strategic
orientation**
defining,
deciding,
debating,
evaluating, …

IV Plan and action
implementing,
coordinating,
monitoring, ...

Figure 4. A typical foresight process.

3.2 Market structures and implications for outlook

Paper II validated hypotheses on the relation between sawnwood consumption per capita (CPC) and a total of 33 potential determinants of demand (see Appendix I). While the estimations suggested that the sawnwood CPC is related to construction activity, income, and prices, the demand determinants appear to be more versatile than what the models based on variables depicting economic activity alone are capable of explaining. In particular, the construction activity variables were unable to fully capture the market behaviour in countries with high sawnwood CPC, where large scale substitution between construction materials and practices seem apparent, presumably caused by technology platforms, government support and the uptake of industrial prefabrication. However, due to the lack of data, the models were unable to verify the cause of the structural changes and the country-specific demand determinants. These factors, based on a review of relevant literature, are summarised in Table 1. It is worth noting that a large number of these drivers seem to be related to social and political factors, such as culture, traditions and the regulatory environment, which may be the most difficult to quantify and measure. However, experts have pointed out that changes in the means of compiling statistics might have also contributed to the apparent structural changes, particularly in the case of a notable structural increase in the sawnwood CPC in Finland in 1990–1995.

Some of the observed differences in the level of sawnwood CPC were found to be possibly explained by the abundance of forest resources. It was hypothesised that in such countries, where the society is able to economically utilise forests, there are active and

Table 1. Factors affecting sawnwood consumption per capita.

Political
- Regulations (e.g., fire regulation)
- Climate and energy policies favouring the use of wood (e.g., public procurement)
- Promotion campaigns and technology platforms
- Zoning and land use planning
Economic
- Cost competitiveness
- Availability of raw material (Forest resources: Abundance, ownership, accessibility, cost, etc.)
Social
- Demographics (e.g., population growth, urbanisation, family size and structure, ageing)
- Willingness of construction networks to adopt new materials and working methods (path dependency)
- Education (sufficiency of wood architects and engineers)
- Awareness of the properties of wood as a construction material
- Perceptions and preferences (WTP for environmental values and renewable materials)
- Attitude towards nature and wood use (significance of the forest sector in the society)
- Traditions and culture
Technological
- Uptake of industrial prefabrication techniques
- Standardisation and certification (e.g., voluntary industrial standards)
Environmental
- Information and regulation on the embodied energy, carbon and raw materials of building products

powerful interest groups, whose aim is to promote and sustain the end uses of forest products. Consequently, the societal interest towards the economic utilisation of forests may help to explain the differences in the sawnwood CPC across Europe and the lack of convergence in the sawnwood markets.

Indeed, the results point to structural changes in the market share of sawnwood most clearly in regions with high sawnwood consumption per capita, low population density, and abundant forest resources. Even though the finding based on past data does not necessarily imply such a connection to hold for the outlook as well, it would seem that it requires less effort for a less populated and more forested country to break the path dependence of construction culture in favour of wood construction. Conversely, it would appear less likely that major market-driven structural changes would occur in larger markets, with a more limited importance of forest resources to the society. As a result, market interventions, such as EU-level policies, promotion campaigns, and technology platforms, may not inevitably result in equal changes in the level of sawnwood CPC across all EU member countries.

The interpretation on the connection between sawnwood CPC and the abundance of forest resources is also supported by the diffusion pattern of WMC in Europe. That is, with few exceptions, the rate of WMC diffusion would seem to have correlated with the level of sawnwood CPC and the market share in detached houses, even though the actors and value chains are mostly separate in the detached house and multi-storey building sectors.

Besides the abundance of forest resources, the lack of convergence in the European sawnwood markets is possibly influenced by the characteristics of the construction sector.

That is, the experts' views in Paper IV strongly supported the literature which characterises the construction sector by a number of path-dependencies. That is, construction was seen to be heavily tied to the local culture and traditions of a region. The structure of the sector encourages incremental improvements only, which can be seen from the scarcity of major changes in the process development of construction since the 1950s. The sector can also be characterised as highly risk-averse. For example, the perceived risks related to new practices are typically budgeted to the profit margins of developers and main contractors, which can make the adoption of new practices unattractive, even if the actual construction costs between the competing construction practices were equal.

The cultural differences may partly be seen in the perceptions towards wood construction, in that the perceptions do not invariably correspond to the measurable technical properties. Based on the review in Paper III, in regions and sectors without long traditions in wood construction, the wood-based construction practices are not necessarily perceived as technically and economically credible alternatives for the conventional construction practices. Rather, wood architecture is perceived as a curiosity where soft values related to health and environment are emphasised. It follows that also the main barriers of large scale diffusion relate to the credibility of wood construction throughout the construction value chain.

Owing to the local culture and structure of the construction sector, the market potential of wood construction in Europe by 2030 appears to be highly region-specific. Table 2 presents an attempt to classify the 15 European countries in the sample according to their wood construction market potential, based on the past trends and current market structures. However, it needs to be noted that the approximate classification does not consider for example the possible regulatory push and pull for green building, which for example seems to have contributed to a significant increase in the market share of WMC in the UK.

Table 2. Market potential of wood construction in selected regions in Europe.

Region	Northern Europe	Central Europe and the UK	Western Europe	Southern and Eastern Europe
Market potential by 2030	High	Intermediate	Low to intermediate	Low
Countries	Finland, Norway, Sweden	Austria, Northern Italy, Southern Germany, Switzerland, The UK	France, Ireland, the Netherlands, Northern Germany	the Czech Republic, Hungary, Poland Southern Italy, Spain

3.3 Alternative futures

The WMC market potential is affected by a variety of trends and uncertainties in the global operational environment and by the means of the construction sector in adapting to the changing conditions. According to construction sector outlook studies reviewed in Paper III, the most significant trends of the 21st century with an impact on the construction sector relate to demographic changes, environmental issues (principally climate change) and the increasing complexity of the global economy, driven by digitalisation and globalisation. In Paper IV the wood construction experts also identified a number of pressures for the construction sector, culminating to the need for improved environmental performance, quality and productivity of construction. However, it is critical to note that the identified pressures do not necessarily translate into competitive advantage for wood construction, due to the possible lack of willingness or ability to pay for the technical or environmental improvements.

The decisive uncertainties for the large scale diffusion of wood construction appear to be the possible changes in (i) the strategy orientations of the wood construction sector to negotiate the cultural and structural hindrances of the construction sector, in (ii) the attitudes of the construction sector towards the uptake of new technologies and processes and in (iii) the regulatory environment, both in terms of removing the regulatory hindrances for increased competition and in terms of taking measures to reduce the negative externalities of construction. By assuming alternative directions for these critical uncertainties, the following paragraphs summarise four alternative scenarios for the WMC sector, each of which implying a different level of WMC diffusion in Europe (see Fig. 5).

In a *business as usual* scenario, the accumulating pressures in the operating environment are to a large extent ignored. That is, the cultural lock-in and traditions prevent other than incremental changes in the construction value chain. The construction sector persists in avoiding perceived financial risks related to new types of projects. The inertia for the uptake of new practices is heightened by the lack of regulatory push for green building. On the other hand, policies aiming to enforce the uptake of wood construction have eventually a similar impact, due to the unwillingness of the industry to comply and the resulting loss of credibility for the supported practices. Consequently, investments in industrial element production remain scarce.

In a *technological supremacy* scenario, numerous new technologies based on for example 3D-printing are emerging. Their adoption is driven by investment schemes pursuing significant improvements in the productivity of construction and the new generation's willingness to experiment with novel construction techniques. As some of these practices are taken into mass production, the WMC practices might catch on only temporarily and only in regions with long traditions in wood construction. Wood construction might be perceived as old-fashioned and unsuitable for large scale construction, other than in less visible surfaces or as a mixture for new generation components. In this setting, the regulatory hindrances for WMC might remain in force, as the regulatory push for green building would be directed towards the most advanced

building technologies only, such as artificial photosynthesis and synthetic biology more in general. The policy pull for advanced materials and systems might not encourage initiating large consortia for the development of WMC practices. Even though the suppliers retain their role as element suppliers, they could possibly establish alliances with main contractors or developers to provide low-cost building solutions for niche markets.

In a *healthy competition* scenario, the regulatory hindrances for the uptake of new practices are revised, with the aim to decrease costs, improve quality, increase the number of choices available, trigger international competition and encourage R&D activities. In addition, the public sector sets stringent functional requirements for the environmental impact of construction. The combined effect of the regulatory push and pull force more competition in the construction sector. The resulting competition sustains the R&D for, and the adoption of, technically and economically superior construction practices through increased co-operation and new business models and financial arrangements. In a more competitive and permissive operating environment, the WMC concepts would have improved chances of succeeding. The growing number of new suppliers allows introducing standardised open systems for WMC, which would eventually lead to gaining enough volume for increased credibility of the sector and for reduced costs and perceived risks. At the same time, the construction industry at large would pursue significant product and process improvements, aiming at a higher rate of industrialisation and improved performance and function. The increased competition would drive down the costs of the novel systems, which would result in a more diverse construction sector compared to that of the beginning of the 21st century.

I n a *new reign of wood* scenario, revising the building regulations and internalising the environmental externalities of building products encourages more investments in wood element production capacity. Moreover, the wood element suppliers are encouraged to take more responsibility in the construction value chain, which effectively negotiates the structural hindrances for the diffusion of wood construction. With an increasing likelihood, the established building practices are unable to respond to the price competition with WMC. As a result, the construction sector begins to show interest towards the economic potential of adopting wood construction practices on a large scale.

ue to the large uncertainty related to the future directions of the underlying drivers, each of the scenarios ought to be equally likely. While the range of stakeholders' expectations for the future mirrored this uncertainty, the average view was that large scale diffusion in the range of tripling the market share by 2030 seems unlikely on the European scale, due to the structural rigidities of the construction sector and the gradual nature of effective measures to be taken (Paper IV). For example, establishing open systems based on standardisation does not even seem possible by 2030. In contrast, the WMC diffusion was seen comparatively likely in the Nordic countries and in the UK (cf. Table 2).

Regardless of the scenario, the implications of the possible WMC diffusion on the demand for forest resources and on the environmental impact of construction would appear to remain rather limited on the European scale towards 2030. That is, according to sensitivity analysis based on a simple spreadsheet model (Paper III), even a 100 % market
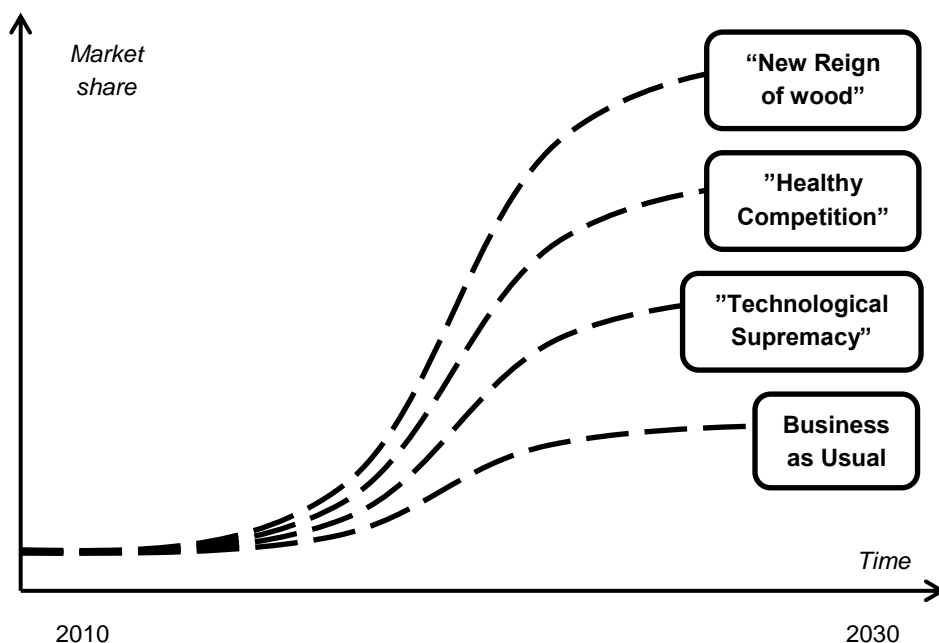
Figure 5. Illustration of the scenarios.

share of WMC would imply a maximum roundwood demand of 10–65 million m^3, which corresponds to maximum 10 % of the net annual increment of forests available for wood supply in the fifteen selected countries (see Table 2). According to a more feasible scenario with a 5 % market share in these fifteen countries, the demand for forest resources for the production of structural frames of multi-storey buildings would not exceed three million cubic metres.

The impact of WMC diffusion on wood resource demand could be even more limited, if considering the possibly declining demand for wooden shuttering for concrete casting. On the other hand, the wood demand for novel fibre reinforcement technologies or 3D-printing could, in principle, exceed the demand for WMC.

In the case of 100 % market share, the calculations suggest a reduction potential of maximum 90 % for the CO_2 emissions in the production of structural frames for residential multi-storey buildings. Full substitution would correspond to 0.5–3.9 % reduction in the total human-induced GHG emissions in the fifteen European countries. That is, even if the relative reduction potential would be significant, the absolute effect of WMC diffusion on the CO_2 emission of construction is likely to remain limited. Moreover, the environmental impact calculations are based on substituting ordinary Portland cement for wood-based products. It follows that the reduction potential would be considerably less significant, if not reverse, should the alkaline activated concrete or other such drastic environmental improvements be adopted in concrete manufacture.

3.4 Private and public sector measures for pursuing green building

Building on the explorative scenario analysis, Paper IV discussed the required measures for realising the wood construction market potential in the context of the industries' long-term targets towards 2030: Tripling the market share of wood construction, doubling the value added of the wood products industries and reducing the embodied carbon of construction products by a third. The three targets themselves as well as the possible measures to pursue them were found to be to a significant extent interlinked.

The wood products industry could negotiate the structural inertia of the construction sector by changes in the roles of actors in the construction value chain. In the Finnish WMC markets, the suppliers and main contractors have established alliances, i.e. bilateral closed systems, to share risks and experiences. However, even though the alliance model was considered to have yielded beneficial experiences, the closed building systems were noted to be in strong contrast to the objective of standardising wood construction practices, which aims at bringing down costs through increased competition within the sector. Clearly the prevalent view was that alliance models are needed in the short-term to improve processes by repetition and learning by doing. The markets will then gradually choose the standards (open systems), possibly in a few decades time. However, although not brought up during the interviews, it would seem that comparing the standardisation of the 21st century WMC techniques to the 1960s concrete element techniques might not be entirely valid, due to the constantly increasing level of complexity of buildings and the expanding possibilities related to information technology.

The open and closed systems depict important means of improving the competitiveness of wood construction by lowering the costs and perceived risks of potential adopters by gradually increasing the number of successful reference projects. However, they do not necessitate further organisational changes. Although explicitly stated by only few interviewees, negotiating the inertia for the diffusion of wood construction might require moving downstream in the construction value chain. As suggested by one interviewee, a partial solution could be for the large forest industry companies to incorporate spin off construction units to allow more flexible and strategic operation. Similarly, another interviewee pointed out that the wood element suppliers could establish a common developer firm specializing in wood construction and acquire the needed expert services. This way, it seems, both the supply and demand side would be made more flexible and increasingly likely to meet each other.

However, the results clearly point out that so far the Finnish wood product industry actors have been unwilling to take more responsibility, even though the planning capacity and know-how required by turn-key supplies positions some of the firms already close to acting as the main contractor. Moreover, the market structures may pose a hindrance for taking this step especially in the Nordic countries, where the markets require partial turn-key supplies that necessitate having large amounts of capital fixed for several years. That is, For example, there were noted to be only few wood product firms, whose turnover exceeds 100 million euros, thereby providing sufficient financial credibility for developing the

sector and for being a reliable partner in alliances. Moreover, the few global forest industry corporations might be too large in order to be interested in the relatively small construction markets in the Nordic countries, compared to the global pulp and paper markets.

The changes in the roles and responsibilities in the construction value chain are directly linked to the value added target, in that the knowledge-intensive planning and management services associated with turn-key supplies would translate into elevated relative employment costs, i.e., value added. Indeed, a number of interviewees maintained that affecting the value added on the scale that the long-term targets suggest would require changes in industry structures and roles in the value chain. Yet clearly the most attractive strategic orientation for affecting the value added was to increase productivity by standardisation and process development related to industrial prefabrication. Consequently, the study was unable to build a satisfactory understanding of such realistic means of meeting the value added target by 2030 that the stakeholders would seem to be committed to, although a balanced emphasis on cost reduction and value adding measures and a focus on certain niches would appear viable.

The ability to meet the targets on market share and environmental impact are to a significant extent dependent on the magnitude and direction of the possible regulatory push and pull for green building. In the absence of regulatory push for green building, the wood products suppliers could aim at raising awareness on the environmental and functional qualities of their products by introducing and deploying environmental product declarations (EPD). However, as noted by the stakeholders, it may be realistic to assume that the EPDs based on international standards would mainly be able to create sectoral image, as the construction sector at large might be uninterested to compete with environmental qualities or indeed other qualities than costs, if not driven by obligation. Some interviewees thought it is imminent that the EPD will become obligatory, for example by integrating it to the CE-mark for construction products. Even though the policy or strategy measures based on information alone were generally thought to have limited impact on the diffusion of new construction practices, the industry stakeholders emphasized the need for inflicting more competition in construction by removing the excessive regulatory obstacles and cost burdens.

Since the costs of construction tend to have the largest influence on the choice of construction practices, the respondents emphasized the need for reflecting the environmental externalities in raw material and commodity prices, with 76 % of the respondents expressing this opinion. Levying a global or EU level carbon tax for first stage production was also supported by 60 % of the respondents. However, somewhat surprisingly, very few experts brought up the fiscal measures during the interviews. Apparently, strong counter lobbying could be expected, due to the large short-term costs accruing to the established industries. Nonetheless, the transport sector was referred to as a useful benchmark for effective environmental regulation. For example, the Euro 6 standard stipulates the maximum emissions for all new cars and in Finland the car markets are subject to progressive taxation based on the level of emissions.

Two thirds of the interviewees explicitly stated that more stringent norms based on obligation are needed in order to push green building on a reasonable time scale. Four interviewees thought that the market access of green building should be guaranteed and supported until reaching an around 20 % market share by the means of for example green public procurement and land use planning. However, the same number of interviewees explicitly suggested avoiding the direct support of single materials, due to the possibly resulting negative publicity, loss of credibility, and strong counter lobbying. The majority thought that rather than highly prescriptive, the norms ought to be functional to allow as diverse solutions as possible. That is, competition would drive technology and process development by producing more options and credibility and reducing costs.

Finally, the need for establishing and updating education in wood construction was clearly seen as a prerequisite for the diffusion of wood construction. That is, it may be more effortless for the new generation to adopt new practices than it is for the established value chain to learn away from the accustomed practices.

Table 3 summarises the alternative strategy and policy orientations in the context of the four scenarios presented in section 3.3.

Table 3. Private and public sector measures supporting each scenario.

Scenario	Strategic orientation	Regulatory environment
Business as usual	- No change	- No change
Technological supremacy	- Alliances, PPPs, and other means of risk allocation between the suppliers and contractors (closed system)	- Uptake of prescriptive environmental regulation (forerunner program or similar)
Healthy competition	- Standardisation to bring more competition within the WMC sector and thereby to bring down costs and make the WMC practices more credible across the value chain (open system)	- Uptake of functional environmental regulation (norms) - Removing regulatory obstacles and cost burdens
New reign of wood	- Wood element suppliers to take more responsibility in the construction value chain	- Introducing fiscal measures based on LCA - Uptake of functional environmental regulation (norms) - Removing regulatory obstacles and cost burdens

4 DISCUSSION

4.1 Contribution of the study

The overall contribution of this study relates to examining the factors influencing the market potential of wood construction in Europe up to 2030, thereby allowing more realistic and versatile scenarios on the wood products industry development and wood construction markets. The results serve particularly long-term outlook studies and impact analysis studies, in which some of the assumptions behind the demand patterns of wood products have remained poorly understood. That is, compared to studies examining the constraints for wood supply (e.g., Verkerk et al. 2011), few studies have considered the plethora of drivers and constraints for the demand for wood-based products and services. Indeed, the mainstream forest sector outlook studies could be criticised for their method-oriented and data-oriented approach, as opposed to a problem-oriented approach (see also Harty et al. 2007; Toppinen and Kuuluvainen 2010), although in some cases this may be due to the lack of available resources.

Even though some of the issues with the forest sector outlook methodology have been commonly acknowledged, they have not been previously critically reviewed nor taken into account by attempting to modify the approaches. The main methodological contribution of the thesis was to point out the main development needs and to take initial steps towards negotiating the issues by exploring alternative research approaches. The analysis of probable, possible and preferable futures through a combination of complementary analytical frameworks and linking top-down and bottom-up factors through explorative and normative scenario analysis would seem to have value. Nonetheless, the exact validity of foresight approaches will remain subject to argument.

4.2 Limitations of the study

The temporal scope of the study extends fifteen years into the future. As none of the assertions on the outlook can be verified at the time of publishing, the hypothetico-deductive method of science could not be applied for the outlook part. It follows that the study may only suggest alternative scenarios based on systematic reasoning, argue on their premises and affecting factors, and discuss their potential magnitude and implications. Accordingly, the results need to be interpreted as a (non-definitive) range of critical issues that need to be considered in decision-making, instead of as the only possible future directions.

Various complexities make it difficult to analyse the future of wood construction on a European scale. Consequently, the scope of the study was narrowed down from one paper to the next. Eventually the study could only analyse one sub-sector and one country with a

satisfactory level of detail, namely the WMC markets (Papers III) in Finland (Paper IV). Yet too broad a scope would not have allowed relevant conclusions to be drawn.

Paper II aimed to develop a model that could reproduce the past sawnwood demand patterns and therefore be used to project the sawnwood market developments. While it seems clear that it did not succeed in this particular endeavour, it is one of the very few studies that have aimed to systematically validate the factors affecting the sawnwood consumption per capita, which allows further research efforts to be directed at more promising avenues.

Indeed, while the study has aimed to occupy a niche that has been less studied, the thesis may mainly yield general findings to direct further research, due to the divergent approaches, material, and research problems in each sub-study. That is, major research problems remain to be tackled within the scope of each paper.

4.3 Comparison to previous studies

With some exceptions, the previous literature appears to support the findings of this study on the types of issues limiting the market potential of wood construction and on the required changes to improve its market position. However, the conclusions of this study seem to challenge some of the previous more optimistic outlook studies, industry positioning papers and policy agendas highlighting such drivers for the diffusion of wood construction that would not necessarily appear to translate into significant market potential.

Previous literature recognises the influence of the structure of the sector on the forest products consumption patterns and the market potential for wood construction. The explanatory power of forest resource endowment on forest products markets has been previously documented in the context of testing the HOV-theorem for net trade (Lundmark 2010), although not with definitive support for all regions (Uusivuori and Tervo, 2002). Mahapatra and Gustavsson (2008) argue that the inertia for the uptake of new construction practices is due to the characteristics of the construction industry and the path dependencies of the established concrete-based building system resulting from the co-evolution of the institutional, technical, and societal dimensions over the past century. Also Nord (2008) points to the strong correlation between the industry structure (construction process) and firm conduct. By referring to the dominant industry structure and the culture of using wood, Jonsson (2009), Mahapatra and Gustavsson (2009) and Mahapatra et al. (2012) also support the finding on the regional differences for the market potential of WMC in Europe. Mahapatra and Gustavsson (2009) further argue that the diffusion of WMC seems most likely in Sweden, followed by Ireland, the UK, Germany and the Netherlands. However, Finland is not covered by these studies, possibly due to the lack of data and the stagnant WMC market development prior to 2011.

In addition to the structural rigidities of the construction sector, previous literature also provides evidence of the risk-averse characteristics of the wood products industry. That is, Hansen et al. (2014) characterise the North American wood products industry as

conservative, which based on the results of this study seems to be appropriate in Europe as well. Indeed, the risk analysis carried out by Lindblad and Schauerte (2015) clearly shows that a minute share of the wood products suppliers operate in a segment with elevated financial or operational risks. Peltola et al. (2007) also share the view that in Finland the wood products industry has been in a subordinate position to the pulp and paper industry. However, each of these studies stress that the as yet unrealised potential for organisational change also represents a possibility for the future.

Indeed, a number of studies point to the need for finding alternative business models (Peltola et al. 2007), such as joint ventures (Parvinen et al. 2009), establishing a developer firm specialising in wood construction (Paronen 2014), and targeting whole construction systems rather than mere component supply (Haapio 2013). In strong contrast to the Finnish WMC markets, the strategy of taking more responsibility in the construction value chain has been found to be a viable business model in Sweden, where the turnkey systems supplier strategy dominates with a share of 80 % of all firms (Brege et al. 2014). Parvinen et al. (2009) also make the case of increasing the value added by organisational changes rather than by cost reduction. They also note that the value added of the Finnish wood products industry has been cut nearly to a half over the period of 1997–2008, due to increased production costs, suggesting that in this sector the target of doubling the value added by 2030 would only denote a return at the level prior to the financial downturn from 2008 onwards.

Similar to the findings on the business models, also the previous studies on the possible policy options seem to support the findings in this study. According to Herczeg et al. (2014), the impact of a mandatory framework for information provision on the environmental performance of construction is difficult to quantify, yet likely to exceed that of voluntary measures. Jennings et al. (2011) go further to suggest that strict mandatory building codes, especially appliance standards such as the Japanese Top Runner program, are required to initiate large enough change in the construction sector towards green building. The view is further supported by Mahapatra and Gustavsson (2009) and Mahapatra et al. (2012), who state that market interventions are needed to promote radical innovations such as wood construction.

Regarding the general outlook, the main conclusion of CEI-Bois (2004) appears to be still valid. It states that there are no major factors that would radically support a significant growth in demand for wood products in Europe, which is why a significant growth in market share needs to be actively created. However, in the passing of a decade, a number of technological advances in industrial prefabrication and regulatory changes have changed the setting to somewhat more positive outlook that could be further improved by the possible uptake of more stringent environmental norms. Nonetheless, also the barriers for the uptake of wood construction identified in CEI-Bois (2004), related to institutional and cultural issues, appear to be still relevant.

The similarity of the conclusions of the studies separated by a decade may suggest that in terms of the factors affecting the market potential of wood construction in Europe, this study only managed to scratch the surface of the vast variety of possible drivers and

strategic orientations. That is, the methods used in this study might not have been able to scrutinise the research problem in a novel manner. For example, conceptualising the means of affecting the value added may require complementary quantitative approaches (e.g., Rosenkranz et al. 2015; Schauerte 2015). However, it is critical to note that the similarity of the results may also point to the gradual nature of changes in the construction sector, which would challenge the most optimistic scenarios for the diffusion of wood construction in Europe.

Indeed, the wood construction outlook by Salovaara (2006), Kristof et al. (2008) and Jonsson (2009) appears somewhat optimistic in the light of the most recent data and the results of this study, related to the gradual nature of changes in the construction sector and the unwillingness of the wood products industry to pursue radical changes in business models. It may be that in a number of these cases, despite the extensive analysis in terms of the issues considered, the systematic assessment of their relative importance has been missing, hence possibly explaining the differences in the issues emphasised.

The roadmap for wood construction towards 2020 provided by Kristof et al. (2008) shows a number of similarities to the one presented in Paper IV, in terms of the pressures that the construction sector is facing. However, it highlights for example sustainable lifestyles in a manner that the findings in this study do not support. That is, according to the results of this study, it is important to note that the structural frame of a building is not a consumer good. It follows that the lifestyle choices of individuals do not affect the choice of the frame material, particularly in large scale construction. Moreover, unlike in Kristof et al. (2008), the stakeholders in this study did not highlight the possibilities related to hybrid materials, chemical modification and nanotechnology, which were not seen to provide competitive advantage towards 2030 on a large scale in a cost competitive manner.

One of the few opposite conclusions compared to this study can be found from Riala and Ilola (2014). They observed that interviewees with most experience on wood construction were more critical towards the diffusion of wood construction, suggesting that successful examples alone are insufficient in aiding the diffusion. However, this interpretation is against most previous studies in which the sample only includes experts from the wood construction value chain, including Paper IV in this study, which concluded that the gradual increase of successful reference projects was seen as the most viable option for promoting wood construction.

Studies based on trend-based scenarios, building either on the conventional demand model (e.g., Jonsson 2013) or on a calculation system (Mantau et al. 2010), tend to conclude that the demand for woody biomass in Europe will vastly exceed the potential supply. Based on the simple spreadsheet model calculations in this study, such drastic increase in the demand for woody biomass is not necessarily foreseen in the context of wood construction in Europe towards 2030. Moreover, these studies typically do not consider the impacts of international trade and the price mechanism, which would clear the gaps between supply and demand. That is, the potential scarcity of resources may lead to increasing prices and possibly increased trade, which in turn reduce domestic demand (Hetemäki and Hänninen 2009).

The extreme assumptions for the level of sawnwood consumption per capita of 1 m^3/capita/a in Europe by 2030, typically used in impact analysis studies (e.g., Eriksson et al. 2012), would appear highly unrealistic based on the results of this study. Furthermore, it seems impossible by increasing the market share of wood in the multi-storey construction sector alone. That is, based on the sensitivity analyses carried out for Paper III, only a 100 % market share for WMC would translate into a modest increase of 0.11 m^3/capita/a. With a more realistic assumption of a 5 % market share of WMC in Europe, the rise in demand for wood products would be less than 0.01 m^3/capita/a.

Finally, the estimates for the reduction potential of embodied carbon of construction products and the wood use implications are very similar to for example those presented by Sathre and Gustavsson (2009) for the EU-25. These estimates ranged between 0.03–1.2 % for total emission reduction and between 12–46 million m^3 for roundwood demand in the case of full market dominance, hence supporting the view that the possible impacts of more realistic scenarios for the WMC diffusion in Europe are likely to remain modest.

4.4 Implications for research

For further empirical research on forest products markets, three important implications emerge. Firstly, it is necessary to differentiate between factors affecting the overall market volume, i.e., economic activity and demographics, and factors affecting market shares, i.e., factors causing substitution. Similarly, a division should be made between long-term structural factors and short-term business cycle factors. It may require estimating different models for long-term variables using cross-sectional data and for short-term variables using time series data. That is, the GDP was found to be one of the few variables that contain sufficient variation in both the time series and cross section dimension of the data.

Secondly, there are severe issues with data quality and availability, both for the dependent and the independent variables. Typically, there are no data available for high value added products and services and newly emerging products and services. Data for the factors explaining substitution also seem to be largely missing. For example, examining the effect of policies on the forest products demand patterns may prove to be difficult, because time series data on for example the amount of resources spent on promotion campaigns in each country may not be available. Moreover, the interpretation of policy dummy variables is subject to significant uncertainty, as wood promotion has occurred in a variety of European countries, yet with various intensities, by various actors and by various means.

Thirdly, the more disaggregated or specific the region studied, the more there appear to be region-specific attributes which the conventional demand models are unable to capture. That is, the European scope appears too broad for the analysis of wood products demand. The same appears to hold for the analysis of the market potential of wood construction, due to significant cultural and institutional differences in construction value chains. The largest meaningful scope for further studies appears to be the three broad market regions: the Nordic countries, Central Europe and Western Europe. However, construction is a very

local business, in that there are differences also between municipalities, which may compromise the ability to draw conclusions even on a country level. Here, the multi-scale scenario approach (e.g., Dermawan et al. 2013) might have value in determining the local implications of global scenarios.

If these points are found to be valid more generally, the findings have implications also for other research that uses the forest sector market models, such as the GFPM (Buongiorno et al. 2003) and the EFI-GTM (Kallio et al. 2004), which use the parameter values from econometric studies as inputs to projections. Accordingly, it would be important to explore, how the approaches and findings of this study on the long-term structural determinants of demand could be incorporated into long-term outlook studies (e.g., UNECE/FAO 2011a).

As one possible research direction for attempting to improve the informational value of outlook studies, the findings of this thesis clearly point to the benefit of combining quantitative and descriptive approaches. That is, models in general provide efficient tools for thinking, yet their operational range is fixed, i.e. there are research problems that the models struggle to cope with. While descriptive approaches are able to consider the variables whose influence the models cannot capture, they are typically based on the judgment of the researcher and they do not yield exact numerical implications on the relationships between variables. For these reasons, it would be intriguing, firstly, to explore whether the conclusions from the alternative lines of research match and which aspects have possibly led to conflicting conclusions (cf. Fortes et al. 2015). With this approach, modelling could reveal insights and connections that would remain unnoticed by using descriptive approaches only, and vice versa. Secondly, the descriptive research might aim to serve modelling more explicitly by feeding variables and specifications on the possible changes in policies, strategies and technologies to be considered in modelling (cf. Hetemäki and Obersteiner 2001).

Although out of the scope of this study, the type of scenarios depicted in Figure 6 would serve as a platform for more elaborate quantification of implications of the potential rate of diffusion of wood construction in Europe. That is, contrary to the typical process of qualitatively interpreting the quantitative outcomes of trend-based scenarios (e.g., Jonsson 2013), it would be possible to quantify the economic and environmental impacts of different levels of possible market diffusion on for example wood use, GHG emissions, value added and market share.

To place the discussion into context, the resource use and GHG emissions of the construction sector should be reduced on a scale of 90 % in the industrialised countries by 2050, in order to effectively contribute to the societal grand challenges, such as keeping the global warming at a maximum of 2 °C (EC 2012, Wiseman et al. 2013). Evidently, even if wood construction would eventually gain near full market dominance, which seems highly unlikely, the environmental impact of the most common building materials must be improved, which calls for novel lines of research also in the context of forest sector outlook studies. That is, further research could aim to more explicitly quantify the realistic contribution of the forest-based sector to the decoupling of resource consumption and the environmental impact of the economy.

Finally, the research gaps were found to include whole research orientations. For example, considering the changing global competitive advantages in primary production and the increasing role of high value-added services in the industrialised countries, the discussion on value added would deserve a novel line of research on its own right (see Näyhä et al. 2015). For example, for many products, the manufacturing process itself generates typically less than 20 % of the total value added, while the services related to the product cover the remainder (see Ali-Yrkkö et al. 2011). These services may consist of, for example, R&D, planning, engineering, programming, financing, commissioning, maintenance, head quarter functions, patenting, licensing, branding and marketing. In the case of high value added wood products or construction systems, it would not make a significant difference in terms of profits, where the manufacturing process takes place. Instead, the location of the related services would matter the most.

4.5 Implications for stakeholders

The structure and culture dependence of construction implies that the market potential in Europe varies by region and by sub-sector. In a business-as-usual scenario with no significant changes in framework conditions, the market potential in terms of growth rate remains to a large extent in novel markets such as in multi-storey and additional storey construction and façade renovation. In terms of growth volume, the largest market potential appears to be in the detached house markets and renovation in Central Europe. In Southern Europe, it may be unrealistic to assume wood construction diffusion, especially in the established markets, other than for example in projects requiring earth quake resistance or lightweight materials. In these regions, it may be more realistic to assume changes in favour of wood on a time scale exceeding 2030, when the definition of wood construction may be changing, plausibly towards the use of wood fibres or wood-based compounds as binding agents for concrete in additive manufacturing and other similar applications. The differences in the framework conditions suggest that also the long-term targets of the industries need to be region and sub-sector specific for them to be properly assessed and for specific actors to assume liability for actions (cf. FTP 2012).

The inertia for the diffusion of wood construction in Europe stems not only from the characteristics of the construction industry, but also from the fragmented structure of the wood products industry and the cautious nature of the strategic orientations. Taking more responsibility in the construction value chain could significantly aid the diffusion, yet this strategic orientation was deemed the least attractive. A similar tension seems to arise from the options for the regulatory push for green building. That is, while policy measures based on competition and information dissemination were seen to yield more credible solutions than norms favouring the use of wood, they could be expected to have influence only in the very long run. Only stricter norms based on functional requirements and fiscal measures would seem to be able to effectively contribute to the diffusion of green building in an acceptable time frame, yet they would probably face strong lobbying, due to the large short-

term costs accruing to the established industries. Consequently, the possibilities for taking advantage of the pressures in the operating environment were seen to be limited in the short-term, suggesting that the diffusion of wood construction in Europe is likely to be a very gradual and long-term process and most likely restricted to certain regions and construction sub-sectors, unless more restrictive environmental norms are introduced.

Although the results do not directly indicate such a conclusion, the cultural and structural hindrances appear to pose a hindrance particularly in the residential construction sector, in which the profit margins tend to be lower and the projects more homogeneous than in other construction sub-sectors. The notion has two implications: Firstly, the market outlook may be less pessimistic for the non-residential markets, in which the profit margins may on average be higher to allow more (perceived) risk. Secondly, in the mass markets it would indeed seem to be a credible strategy to gradually increase the number of successful reference projects and thereby reduce the perceived risks of construction professionals.

The conclusion leaves the question, how the public sector and the wood construction industry can relate to the outlook. On one hand, the targets could be lowered or split into more easily manageable sub-targets. On the other hand, the industries could change their strategic orientations, despite the perceived risks related to unfamiliar business models, if the possible rewards were seen to outweigh the risks of inaction and the resulting gradually weakening competitiveness in the established markets. Also, the range of policy options raised in this study cannot be regarded as exhaustive. It follows that despite the structural and cultural constraints for the uptake of wood construction, there are a number of uncertainties that leave room for the markets to prove the conclusion unfounded.

Finally, it needs to be noted that the research setting in the study has been tendentiously simplified in terms of the competition between wood and other materials. That is, wood is not used in isolation of other materials, which implies that the focus in the development efforts ought to be on optimising the use of different materials in construction. Moreover, irrespective of the diffusion rate of wood construction, the economic and environmental performance of the most common building materials must be improved in order to inflict changes in the order of magnitude that the targets reviewed in this study would imply.

5 CONCLUSIONS

The objectives of the study were to determine the structure and past trends, explore the future trends and uncertainties, and discuss the measures for meeting the targets of the European wood construction sector towards 2030.

Wood construction would seem to be technically and economically competitive against the established construction practices. However, large scale diffusion of wood construction in Europe seems to be restricted by cultural and structural hindrances, culminating to the fragmented and risk-averse characteristics of the construction industry and the traditions and norms related to the use of wood in construction. Consequently, there are significant differences in the market potential of wood construction from one sub-sector and from one region to another. The results suggest that the diffusion of wood-frame multi-storey construction in Europe is the most likely in the Nordic countries and some parts of Central Europe, owing to the societal interest towards utilising the abundant domestic forest resources in high value-added industrial applications.

The construction sector is facing several pressures, related primarily to the quality, productivity and environmental impact of construction. The decisive driver in terms of the future market potential of wood construction was seen to be the possible regulatory push for green building. That is, while policy measures based on competition and information dissemination would be likely to yield more credible solutions than more stringent norms and fiscal measures, only obligatory measures were seen to be able to effectively contribute to the diffusion of green building by 2030. While a number of stakeholders regarded policies explicitly promoting wood construction as necessary, they were pointed out to potentially cause negative publicity and strong counter lobbying, which could lead to a severe loss of credibility for the emerging concepts.

Particularly in the Finnish wood-frame multi-storey construction markets, the ability of the wood element suppliers to pursue a higher market share and value added in the short-run would seem to be dependent on changes in the responsibilities across the construction value chain. However, the industry stakeholders clearly preferred such strategic orientations that allow them to retain their role as component or element suppliers. Accordingly, the most credible and attractive means of promoting wood construction were seen to be to lower the perceived risks of potential adopters and the costs of construction by developing the existing processes and gradually increasing the number of successful reference projects.

The results point to the conclusion that the diffusion of wood construction in Europe will be a gradual process, subject to significant inertia and restricted to a few niche sub-sectors and regions towards 2030. However, the conclusion does not consider the seemingly unlikely, yet possible effects of major changes in the nature of industry strategies and environmental policies. In the end, the value of foresight stems from an improved understanding of the present situation, which may trigger informed decisions that influence the outlook.

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Appendix I

Variables used in the empirical analysis on sawnwood consumption per capita.

Variable	Unit	Source	H_0	r [a]	Excl. [b]	Proxy [c]
Variables included in the final model specification						
Coniferous sawnwood consumption per capita	m^3 / 1000 individuals	FAOStat, World Bank				
Domestic price of sawnwood	USD / m^3 (real)	FAOStat, UN	-	0.17		
Domestic price of wood-based panels	USD / m^3 (real)	FAOStat, UN	+	0.30		
Domestic price of Portland cement	€ / ton (real)	OECD, UN	-	-0.13		
GDP per capita	USD / 1000 individuals (real)	UN	+	0.46		
Renovation and modernisation activity in residential sector	€ / 1000 individuals (real)	Euroconstruct, World Bank, Statistics Estonia	+	0.31		
Residential construction activity	€ / 1000 individuals (real)	Euroconstruct, World Bank, Statistics Estonia	+	0.46		
Residential construction activity (Finland only)	Building permits (2005 = 100)	OECD	+	-0.22		
Unemployment	% of total labour force	World Bank	-	-0.39		
Economic openness; share of trade of total economic activity	% (trade of GDP)	World Bank	+	0.23		
Variables excluded from the final model specification						
Export price of sawnwood	€ / m^3 (real)	FAOStat, UN	-	-0.18	1, 3	
Import price of sawnwood	€ / m^3 (real)	FAOStat, UN	-	-0.13	1, 3	
Relative price of sawnwood (ratio of import and domestic price)	Ratio	FAOStat, UN	-	-0.08	1, 4	
Price ratio of sawnwood and cement	Ratio	FAOStat, OECD, UN	+	0.07	1, 4	1
Price ratio of sawnwood and wood-based panels	Ratio	FAOStat, UN	-	-0.16	1, 4	1
Construction activity in detached houses	Number of completed single and double family dwellings per 10,000 individuals	Euroconstruct, World Bank, Statistics Estonia	+	0.12	1, 3	
Ratio of single-family houses to multi-family dwellings	% of total	Euroconstruct	+	0.01	1, 3	
Size of households (families)	people / dwelling	Euroconstruct	-	-0.58	2, 3	
Industrial coniferous roundwood production	m^3 / capita	FAOStat, World Bank	+	0.75	1, 5	2
Growing stock of coniferous wood	m^3 / capita	UNECE, FOREST EUROPE	+	0.72	1, 5	2
Climate (Heating Degree Days)	°C * days at certain thresholds	Eurostat	+	0.72	1, 5	2
Population density	people / km^2	UN	-	-0.62	1, 5	2

Variable	Unit	Source	H_0	r[a]	Excl.[b]	Proxy[c]
Protected land area	% of total land area	World Bank	-	0.02	3, 5	2
Share of combustible renewable materials in energy consumption	% of total energy consumption	World Bank	+	0.64	1, 5	2
Ratio of forest sector exports to GDP	%	FAOStat	+	0.66	1, 5	2
Domestic price of pulpwood	€ / ton (real)	FAOStat	+	-0.24	4, 5	3
Gross fixed capital formation	billion USD / capita (real)	UN	+	0.36	1, 2	4
Household consumption expenditure	billion USD / capita (real)	UN	+	0.23	1, 2	4
Value added of the construction sector	billion USD / capita (real)	UN	+	0.29	1, 2	4
Ageing	% of population over 65 years	UN	-	0.28	3, 4	4
Urbanisation	% of population living in urban centres	UN	-	0.49	3, 4	2
ISO 14001 certificates	Cumulative number of ISO 14001 certificates / million individuals	ISO	+	0.21	3	2
Patents for secondary processed products	Number of patents (Nace R1: DD20)	Eurostat	+	-0.02	3, 4	
Government bond yield	% per annum	IMF	-	-0.17	3	4
Dummy	1/0		+		2, 4	5

[a] The sample period for the Pearson correlations (r) varies due to restricted data availability

[b] Reason for excluding: 1) overlap, 2) multicollinearity, 3) weak explanatory power, 4) equivocal effects, 5) endogeneity

[c] Proxy for: 1) Substitution, 2) Forest resource endowment; significance of the forest sector for the society; culture, 3) Integration of roundwood markets, 4) Economic activity, 5) Policies

Appendix II

Key assumptions for impact analysis.

Factor	Variable	Source	Value
Wood resource consumption			
Construction activity (based on data from 1985–2012)	Number of apartment completions	Euroconstruct	0.5–1.5 million
Size of apartments	m^2 per apartment	Tolppanen (2015), Statistics Finland	56–78
Wood use coefficient, coniferous sawnwood	m^3 input per m^3 output	UNECE/FAO (2010)	1.97–2.5
Wood use coefficient, glulam and CLT	m^3 input per m^3 output	Taylor et al. (2012)	1.33–2
Material use intensity (amount of material per floor area)			
Wood use intensity in WMC	m^3 / m^2	Nurro consulting, finished projects	0.22–0.58
Concrete use intensity in WMC	m^3 / m^2	Nurro consulting	0.26
Gypsum plaster intensity in WMC	m^3 / m^2	Nurro consulting	0.1
Concrete use intensity (baseline)	m^3 / m^2	Nurro consulting	0.66
Material density			
Coniferous sawnwood shipping density (12 % moisture)	kg / m^3	UNECE/FAO (2010), Hammond and Jones (2011)	430–510
CLT density (Spruce, oven dry)	kg / m^3	Karacabeyli and Douglas (2013)	460
Reinforced concrete density	kg / m^3	Hammond and Jones (2011)	2300
Gypsum plaster density	kg / m^3	Hammond and Jones (2011)	800
Carbon content of wood			
Share of carbon of wood material	% of weight	Sathre and O'Connor (2010)	50 %
Conversion factor from carbon mass to CO_2 mass	ratio	Sathre and O'Connor (2010)	3.67
Embodied carbon (emitted carbon in building product production)			
Coniferous sawnwood	ton CO_2eq. / m^3	Hammond and Jones (2011)	0.09
Glulam	ton CO_2eq. / m^3	Hammond and Jones (2011)	0.19
Cement	ton CO_2eq. / m^3	Hammond and Jones (2011)	1.70
Gypsum plaster	ton CO_2eq. / m^3	Hammond and Jones (2011)	0.31

Appendix III

Interview frame

Background
1. What is your experience in wood construction?
   a. Detached house or large scale construction markets?
   b. International experience?

Drivers and barriers
2. What are the key aspects and who are the key actors that influence the choice of construction practice or material?
3. What kind of pressures or opportunities are emerging for the construction sector?
4. Which critical barriers or hindrances are there for bringing new solutions to the construction markets?
   a. Regulations and building codes?
   b. Cultural issues?
   c. Technical and economic issues (competitiveness)?
   d. Other?

Required changes
5. Which key options are there for improving the market position of wood-based construction practices?
6. Which key options are there for reducing the environmental impact of construction?
7. What would be the critical changes to make it easier for new practices to penetrate the construction markets, either within the sector or in the operational environment?
   a. in the short-term (1–5 years)
   b. in the long-term (5–15 years)

Summary
8. How realistic do you consider the target of tripling the market share of wood construction by 2030?
9. Is there something important concerning this subject not mentioned that you would like to add?