FIRENWOOD

Improved fire design of engineered wood systems in buildings

Obstacles and possibilities in implementation and use of engineered wood systems in construction

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1 Executive Summary

The aim of this report is to identify barriers and new strategies for the implementation and use of wood-based systems in the building industry. A complete list of parameters that have a negative impact on a widespread application for timber construction is potentially infinite and depends on the people, regions and views involved.

Many of the obstacles identified can be attributed to a lack of knowledge about wood as a building material. For this reason, information campaigns and better further training opportunities must be created. Another possibility is the development and provision of standard solutions as well as component catalogues and experience reports of already completed projects. Missing limit values and gaps in standardization lead to uncertainty and non-application. For this reason, further research work is necessary to close any gaps in knowledge and to increase safety in timber construction. A higher CO_2 price within the EU emissions trading system can help timber construction to gain a higher market share due to its function as a CO_2 storage. Therefore, greater consideration of environmental aspects in building construction is necessary.

2 Introduction

The most important trends of the 21st century concern demographic changes, environmental issues (especially climate change) and the increasing complexity of the global economy driven by digitalisation. The world population is expected to grow to around 9.7 billion people by 2050, compared to about 7.2 billion today (Department of Economic and Social affairs 2019). Due to population growth, the demand for housing, goods, energy and food is expected to increase, leading to a growing scarcity of natural resources. Negative effects on the climate due to the increasing use of fossil energy cannot be ruled out either. For this reason there is a need for resource efficiency and the decoupling of economic growth from the use of non-renewable resources.

The construction industry is the most resource-intensive sector in the global economy. Worldwide, the construction and use of buildings accounts for half of all resource and energy consumption and one third of water consumption. It also generates one third of all waste (European Commission 2014b). Reducing the intensity of resource use in construction is therefore important to maintain industrial and economic resilience.

One means of adapting to the scarcity of resources is the use of wood as a renewable raw material. The market share of timber construction in the construction of single-family homes in Europe has averaged around 8-10% in recent decades (Alderman 2013). However, it varies regionally, from over 80% in the Nordic countries to almost 0% in a number of southern European countries. In the markets for multi-family housing, an average market share of 5% timber is assumed, with most of this being in buildings with two or one (Sathre und Gustavsson 2009). The lack of consistent data on the use of wood in multi-storey buildings suggests that the market share in the segment of three-storey and higher buildings is likely to be below 1% on average, although there are significant regional differences in these markets as well (Jonsson 2009).

For example, the use of wood as a building material in the construction industry in the past has led to barriers to its use in buildings due to its organic origin and the associated flammability. Due to the already noticeable consequences of climate change, however, wood is increasingly being used again as a load-bearing structure for houses.

The report aims to clarify the reasons for the low market share of timber construction and to identify these barriers in detail. At the same time, possible solutions and recommendations for action will be discussed in order to overcome barriers and to show the potential for timber construction.

The report is based on various studies, surveys and scientific researches that were carried out in different countries and are summarized here. In addition to countries from the EU, EEA and EFTA, results from the USA, Canada, Japan, Australia and New Zealand that may concern European countries are also included. A detailed breakdown of the different countries from the individual literature sources is provided in Appendix A.4.

3 Barriers and perceptions

A study carried out in Ontario, Canada, in which 47 non-residential buildings are considered, showed that 81% of these buildings could have been made with timber constructions. However, only 18% had actually used wood (O`Connor 2006). This raises the questions of why the builders decided not to use the material and how a higher rate of timber construction can be achieved. Furthermore, it has to be clarified whether this consideration also applies to European countries or whether other framework conditions exist.

In the following, the individual points that limit the widespread use of wood as a building material in load-bearing structures will be considered. The problem here is that different conditions and boundary conditions exist at national level, which make cross-border obstacles difficult to grasp. For this reason, an attempt is made to provide a general overview and to exclude aspects that are limited to national boundaries. As a consequence, further obstacles may exist, which are not dealt with in this report.

For example, a comprehensive list of obstacles to timber construction in Germany was compiled within the framework of the THG timber construction research project, to which reference is made here (Hafner et al. 2017). However, since Germany has different regulations and traditions regarding buildings, the situation is difficult to compare with that of Italy, for example.

(Gosselin et al. 2017) show in their work the frequency of mainly mentioned reasons for and against the decision of using timber construction in projects on the basis of 13 global projects and 53 scientific articles dealing with the topic. The third source of this report was the complete minutes of meetings of nine non-residential timber construction projects in Quebec, Canada, which is rather irrelevant for this report because of its regional specification. A rough overview of the relevant aspects can already be seen from the global data analysis. The frequency with which individual categories are mentioned is shown in Figure 3-1. The main categories of motivations for timber construction are shown to the left and the obstacles to the right in the figure.

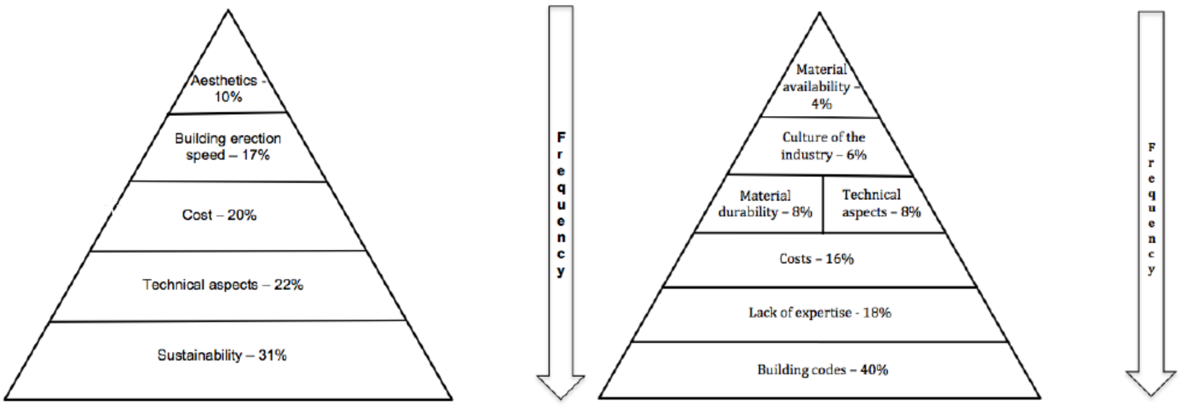

Figure 3-1 Main motivations (left figure) and barriers (right figure) for timber constructions and their relative weight in terms of frequency (Gosselin et al. 2017)

The points mentioned and additional points are dealt with in more detail below. However, it can be seen that some efforts have already been made in some countries to show and summarise barriers to timber construction. Surveys carried out in the timber construction sector usually do not refer to specific products. Moreover, they are often, and to varying degrees, addressed to different stakeholders, making it difficult to present a general view. In addition, regional influences affect the experiences and perceptions of individual stakeholders, since timber construction has a different market share and distribution in this area. Furthermore, buildings are very complex products in terms of materials and their composites and are expensive. This makes generalisations of individual points more difficult to implement, as there are different experiences, levels of knowledge, construction methods, requirements, etc., which influence the answers in national surveys.

For this reason, it is difficult to divide and combine individual aspects into superordinate areas, as these can affect and overlap each other. Especially due to the national differences in requirements, actors, boundary conditions and interests, the process of weighting and linking individual parameters and topics is extremely complex.

This report attempts to create a clear presentation and structure by differentiating into four main points, which nevertheless contain the most important findings from the collected data and concern all EU member states as well as EEA and EFTA member states. These are shown in Figure 3-2. However, some of the barriers they contain may also be attributable to other main points or may influence some parts of them.

A combination of the surveys considered and their results is not regarded as meaningful, as often differentiated questions are asked or the surveys are conducted in a different context or with a different background. An evaluation of the influence of certain barriers on the markets is also difficult, firstly because data on this topic is only available in isolated cases and secondly because individual factors are highly interdependent. Furthermore, the existing system of the EU with its 27 member states also results in 27 different originating situations that differ from each other (e.g. forest area, GDP, population, etc.), which is why a standardisation of the effects of certain influences is not considered to be expedient. For this reason, the report attempts to identify the potentially most frequently mentioned barriers and to present solution concepts. There is a summary in table form provided in Appendix A.1 with all the barriers to timber construction mentioned in the used literature, which also contains further points that are not dealt with in detail in the report.

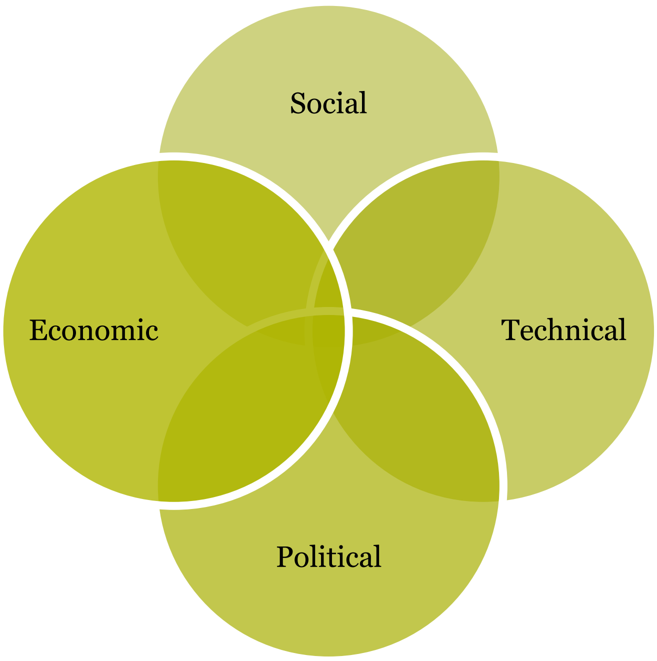

Figure 3-2: The four categories selected for obstacles in timber construction

3.1 Social barriers

3.1.1 Public perception

Wood as a material is perceived differently in the population. The material enjoys an image as a natural and sustainable (renewable) product. However, attitudes towards forestry in an increasingly environmentally and sustainability-aware population can be a significant barrier to increased timber use in construction projects, as a high rate of logging due to increased demand for multi-storey timber structures can lead to rejection of them because of concerns against deforestation. At the same time, timber as a construction product often is considered inferior to steel, brick and concrete construction. There is also the view that building with wood is an "old-fashioned" construction method (and an old-fashioned material) compared to concrete and steel, which can lead to potential hurdles for an uninformed public to accept the construction method. Concerns are expressed primarily about the flammability, durability, dimensional stability, resistance to rot and insects, and the more expensive maintenance costs (Rametsteiner und Oberwimmer 2007).

A key component for the progress of the timber construction industry is the understanding of the markets and negative perceptions related to the use of wood. This includes fire hazard, acoustic performance and robustness, as there is still considerable public concern about the combustibility and durability (decay) of wood as a natural building material. These properties are perceived as disadvantageous compared to steel and concrete constructions (Kremer und Symmons 2016). In fact, in the event of a fire, wood chars at a uniform velocity depending on the type of wood so that its load-bearing capacity and susceptibility to collapse in a fire situation can be accurately predicted. This helps, for example, in the work of rescue services. The required structural fire resistance is achieved with structural protective cladding - usually plasterboard - and thicker cross-sections to allow for charring. In the event of a fire, the absorbed moisture in a plasterboard evaporates and keeps the temperature of the board on the side opposite the fire low, preventing the wood from igniting. Cavities in the structure can be filled with non-combustible insulating material, which protects the wooden structures and slows down the charring of the wood.

To overcome such prejudices, communication through marketing should make it very clear how timber construction works and why there should not be any concerns about the durability of timber buildings. It should also be made clear what positive fire properties wood has in comparison to steel, for example, since the failure of the load-bearing structure can be dimensioned relatively easily due to the predictable burning and the low rate of burning due to the forming carbon layer. In addition, other systems are available to delay the ignition of wood (by encapsulation or application of fire retardants) or which can lead to an early extinction of a fire (e.g. sprinkler system). Awareness campaigns on wood treatment in multi-storey timber buildings are therefore of crucial importance to prevent negative attitudes that deter potential buyers of timber buildings. Real estate agents and developers must inform consumers about the properties in order to overcome existing prejudices.

Given that a large majority of Europeans are concerned about climate change (European Commission 2014a), measures must be taken to replace greenhouse gas-intensive materials with climate-neutral materials. This principle should be supported by public opinion. (Rametsteiner und Oberwimmer 2007) try to clarify, on the basis of several surveys carried out, to what extent consumers agree with the widespread expert opinion that the use of wood contributes to the mitigation of climate change. Here it becomes clear that the people questioned are rather undecided. Respondents tend to consider wood to be ecologically better than materials such as concrete and steel (see Figure 3-3). However, it should be noted that many of those questioned do not have the necessary specialist knowledge and had only limited opportunities to form a well-informed opinion on this topic. It is therefore likely that a certain number of respondents followed the statement of the thesis.

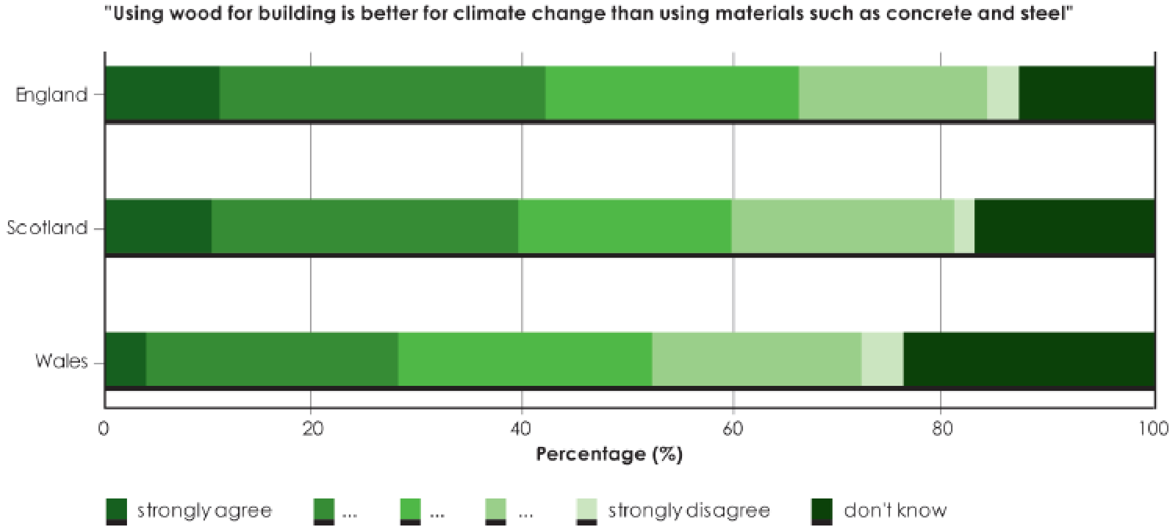

Figure 3-3: Diagram in survey of UK Forestry Commission to the thesis: "Using wood for building is better for climate change than using materials such as concrete and steel" (Forestry Statistics 2007)

It is also conceivable that builders and developers do not mention the use of wood as a primary building material. Since the external and internal treatment of the structure is similar to that of conventional construction, consumers might not even notice the wooden structure. However, if the use of wood is not mentioned or not noticed in the final product, the possibility of promoting a number of environmentally friendly construction features and benefits (carbon sequestration and lower emissions) is lost.

Due to the lack of knowledge and information about timber construction and its environmental impact, it is necessary to create communication opportunities that spread information about the sustainability and quality benefits of timber construction. Promotion and information programmes are conceivable here to overcome the ignorance and reservations of consumers.

Due to the increased environmental awareness, the social perception of building products and the manufacturing industry is an important factor in the spread of timber construction. Consumers are interested in the social behaviour of organisations, which may influence purchasing behaviour or decision making. For consumers, a key link in the purchasing decision process is the level of trust between the brand and reputation of the organisation and the consumers who buy its products (Castaldo et al. 2009). Organisations with a socially oriented philosophy are able to use their positive reputation to market products with a higher symbolic value - as in the case of timber construction, for example, to be more sustainable than traditional construction methods. The use of concise marketing messages about sustainable forest use, including forestry, product manufacturing, building use and disposal, is therefore crucial to ensure the acceptance of wood building products in the marketplace.

But even if consumers were prepared to pay a premium for environmental or health benefits, the introduction of construction methods would mostly depend on the attitude of developers, designers and contractors (see also chapter 2.1.2 Stakeholders). In general, the choice of material is still trivial for the consumer compared to the price, location and floor plan of the dwelling (Hurmekoski et al. 2015). Sustainability considerations alone therefore do not provide sufficient motivation for timber construction when weighed against the disadvantages due to the lack of commercial opportunities. Nevertheless, it is important to raise the awareness of potential consumers towards timber construction, as the decision in favour of a more climate-friendly material can be made with only a small increase in costs. At the same time, this also increases the knowledge within the consumer group about the available options. Further research on the potential of timber construction in the field of sustainability and health is also necessary in order to achieve a broad argumentation basis for the promotion and acceptance of multi-storey timber construction.

A further problem may be the lack of knowledge in the population of certification systems for buildings. These systems were developed in order to be able to evaluate ecological, economic and social qualities of buildings and to make comparisons possible. Various certification systems have been established internationally. They assess buildings on the basis of a certain catalogue of criteria, but weight them differently and use the respective national standards and regulations. For building owners, it is also an opportunity to increase their competitiveness and marketing opportunities through a positive image based on the certification system. Furthermore, building certification is an information opportunity that can make visible the influence and opportunities of the building industry in relation to global developments such as climate change and scarcity of resources.

A low level of awareness of the systems among the population reduces their desired effects for building owners. For this reason, it seems to make sense to introduce mandatory certification systems for public buildings in order to promote sustainable building methods such as timber construction and at the same time increase the level of awareness of these systems. In this way, the signal effect will reach broader sections of the population who will receive information on sustainable construction methods. Consumers should understand the qualities of the property and be informed about how this contributes to environmental efforts.

3.1.2 Stakeholders

The process of material selection during the design phase can be described as complex, as many actors are involved in the decision phase (e.g. architects, structural engineers, contractors, end-users) (Bysheim und Nyrud 2008). Important stakeholders for timber construction are, besides the client, especially the architects, as they can also have a stronger influence on the choice of materials (Leonard et al. 2009) (see Figure 3-4). However, their opinion is difficult to categorise, as it depends on their respective roles within a construction project and the awarding procedures differ in the individual countries. As a result, the influence of the individual actors can vary across countries (Januzi-Cana 2017).

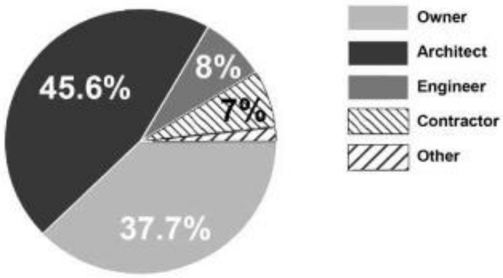

Figure 3-4: Entity with the most influence on steering a project to timber (Leonard et al. 2009)

(Denizou et al. 2007) investigated the mechanisms that influence the material selection process, with a focus on the use of wood in urban development. In cases where wood is used, dedicated architects and/or consultants are a common denominator. In cases where wood is not used and where the architect can largely control the material selection process, aesthetic considerations are a decisive factor. Contractors emphasise tradition, competence and access to competent craftsmen as important factors in the material selection process. Wood is not considered suitable for buildings above three storeys. The use of wood is perceived as difficult and expensive, and the flammable properties also have a negative influence on the use of wood.

Overall it can therefore be said that architects play an important role in the design process, but the choice of material is often finalised by the client and the building owner (Bysheim und Nyrud 2008).

These decision-makers may therefore be a decisive barrier to the spread of multi-storey timber construction. If the decision-makers lack the specialist knowledge for timber construction due to a lack of tradition or training opportunities, or if they are not motivated by the high restrictions imposed by the respective building regulations, it follows logically that a decision will be made in favour of classical construction methods (Gosselin et al. 2017).

The construction industry is generally described as risk-averse, more fragmented and path dependent than many other economic sectors (Arora et al. 2014). The conservative and cost-oriented nature of the construction industry has shown that stakeholders are reluctant to use new sustainable materials or technologies if they have to accept the consequences of failure. As a result, new materials, technologies or practices often face significant barriers to market entry and expansion (Giesekam et al. 2014) and familiar practices are preferred to alternatives because of existing standards and institutions. As a result, an unconventional approach tends to become more expensive for the end customer, even if the actual purchase price is comparable. A company that tries to minimize costs and financial risk would therefore lack the motivation for such an approach. Furthermore, the life cycle of buildings is longer (30 to 100 years) compared to consumer goods. The commercialisation of new products, processes or business models on the markets typically takes several decades (Hurmekoski et al. 2015). Projects based on cost competition only promote innovation gradually and easily lead decision-makers not to accept new practices that may cause additional effort and associated costs in the short term

Traditionally, price, schedule and quality have been the criteria for the success of projects. But for construction projects, additional criteria such as environmental impact, innovation and working environment should be used as additional criteria to facilitate market access and strengthen timber construction. Furthermore, information gaps of decision-makers in relation to multi-storey timber construction must be closed. As there is usually little or no experience in the field of timber construction, it is often decided not to implement timber constructions. For this reason, access to specialist information for non-specialist stakeholders is crucial. The continuous development and publication of component catalogues, which also cover connection and connection detailing, can be helpful. In addition, design tools are conceivable that provide a simpler understanding of the subject matter.

Another possibility is a simplified access to research results. A collection of experience reports and project results from already completed public sector construction projects also represent basic methods for the provision of information.

The support programmes must be supplemented by instruments of information to overcome the lack of knowledge and reservations of building planners, consumers, building inspection authorities and financiers. Significant promotion of timber construction, including research promotion, would also send out signals to universities and engineering colleges to anchor modern timber construction more firmly in teaching, so that the relevant background knowledge is available to future architects and building planners.

3.2 Technical and performance related barriers

3.2.1 Knowledge and Experience

In the scientific articles evaluated, the lack of knowledge of the people involved in construction (architects, engineers, supervisory authorities, etc.) is often given as a reason when the decision is made against the use of timber construction in built projects (Gosselin et al. 2017). However, there are national differences, which are probably related to the experience of the individual countries in the field of timber engineering.

Most designers are more familiar with concrete and masonry structures than with timber structures. Especially in countries where there is no tradition of timber construction, there is a lack of experience and expertise of designers in the physical and mechanical properties of timber (strength, durability, deterioration, sound, wind bracing, insulation, ease of use, maintenance, etc.). So if builders want to build with wood, it will cost more than with traditional materials, because they need experienced designers, especially from abroad, and because complex uncommon techniques and trained staff are needed for production, construction and maintenance, which increase the cost of each step. It would be ideal for the design process if the project team has experience both with the specific structural system and with working as a team. Currently there is only a limited number of designers with experience in timber construction and a limited number of projects that have been realised. Considering that the structural systems are still under development and that several different systems coexist, it is difficult to obtain full information (Ruuska und Häkkinen 2016).

There is also a lack of in-depth knowledge of the building regulations relevant to the use of wood in construction (Östman und Källsner 2011), as the requirements for buildings differ from country to country. For this reason, increased planning efforts are to be expected, especially if designers are not familiar with the different national rules, which can lead to uncertainties and delays.

Another problem mentioned is the insufficient transfer of knowledge between research institutions and industry. In multi-storey timber construction it is of utmost importance that all stakeholders actively participate and contribute to the development of timber construction technology and systems. Large-scale timber construction has been experiencing an upswing in many European countries for some time (Hynynen 2016) (Bengtsson 2009). In this phase, technology and systems continue to develop rapidly and many of the players in the market have limited knowledge and experience with existing products. There is still only a small number of suppliers, but it is growing steadily. Timber construction differs from traditional construction methods because many construction projects are carried out with new technology and new systems, which make them learning projects. This means that all actors in the areas of project development and implementation must work together. Successful projects have to be organised in such a way that the actors (landowner/community, builder, architect, system supplier, installers, planners) work collectively already in the programme and planning phase. There is a great need to document and ensure feedback of experience in the fields of building systems, installation methods and management in order to improve technologies and systems and to build up data bases. Uncertainties in terms of technology require designers and architects to be more willing and flexible throughout the project. It is difficult to achieve economies of scale for all new technologies and systems at an early stage.

From the available studies it is clear that building traditions and established practice are significant institutional barriers. The introduction of systematic innovation is generally hampered by the decentralised nature of the industry and varies both regionally and between companies of different sizes. As a result, individual firms or subsectors often establish specific workflows and material pallets that are used in all projects, which can anchor a culture of building in specific materials and discourage professionals in the construction industry from seeking or experimenting with new materials or practices. Change in established cultures can only be achieved through effective knowledge sharing. The effective dissemination of information on alternative materials, technologies and practices is crucial to bridge the gap between prejudice and knowledge. This information is often scattered across many publications and online sources and is rarely coherently brought together and presented to practitioners and policy makers. The effective transfer of research results from academia to industry, together with the formation of effective industry association and knowledge centres, is critical to promoting acceptance. Increased training at universities or public educational institutions in the field of timber construction and associated with fire safety can also promote the dissemination of expertise. To this end, timber construction should be established as a compulsory constructive subject in the training of architects and engineers.

In addition to the lack of expertise in timber construction, a lack of available data and information sources for training purposes and a lack of demonstration projects are also seen as obstacles (Franzini et al. 2018). A common solution to overcome this lack of information is to provide more information to decision makers. For this purpose, training opportunities are to be created, which can bring topics concerning timber construction closer to interested parties. Furthermore, detailed and component catalogues offer additional potential to be used as a source of information. For this purpose, an easily accessible platform must be created, which contains project and experience reports in addition to the component structures and connection details, as well as enabling communication between the interested parties. This can make it easier for planners and decision-makers to recognize the feasibility of a project and the market potential.

3.2.2 Timber construction industry

The timber construction industry is generally made up of small to medium-sized construction companies (Sardén Ylva 2005). The following Table 3-1 shows an example of the structure of the branches of the commercial enterprises operating in Germany with the main focus on "carpentry and timber construction".

Table 3-1: Branch structure of commercial enterprises with the main focus of business "carpentry and timber construction" in Germany (Rainer Kabelitz-Ciré 2019)

2018	Total	1 - 4	5 - 9	10 - 19	20 - 49	50 + ...
Employees	67905	13076	19436	20981	11412	3000
Companies	11435	6470	2920	1593	416	36
Employees/Companies	5,9	2	6,7	13,2	27,4	83,3

The efficiency of the companies appears to be problematic in the case of an increasing demand in the timber construction sector. All companies involved in timber production and their capacity utilization must be taken into account. This applies not only to the production sites but also to the sawmills, forestry and the suppliers. In addition, the experience of the companies is an important requirement for the realisation of more complex multi-storey buildings.

If the capacity utilization of the individual plants is already high, an increase in demand can lead to capacity bottlenecks and ultimately to higher prices, which can make timber construction no longer competitive with traditional construction methods. In addition, delays in schedules and construction processes can occur, as the companies are no longer able to adequately meet the increased demand.

The establishment of new companies to cover the increased demand is therefore difficult, because in addition to the high investment costs, the corresponding know-how must also be available for the production facility. This covers not only the plant technology via the production line and the necessary machines with regard to prefabrication, but also knowledge of the materials used, their machinability and various quality controls.

A further obstacle is seen in the structure of the described value chain of wood products. Between the raw product in the sawmill and the final product in the factory, a number of players are involved. This fragmentation of the value chain has contributed to a lack of long-term market orientation. This has weakened the position of wood as a building material compared to traditional building materials such as steel and concrete (Sardén Ylva 2005).

The location of a production facility is also problematic. It must have good connections in order to be able to transport the raw materials and the manufactured building products. Furthermore, it should have a certain proximity to sawmills in order to shorten transport distances and deepen the value chain. At the same time, a central location to supply large markets is also desirable. In Europe these are Germany, Austria, Switzerland, Great Britain and Scandinavia (Hurmekoski et al. 2015). For this reason, it is unlikely that in countries without their own market potential or large forestry areas, manufacturers or stakeholders will be able to establish their own timber construction production, which will make it more difficult to expand the timber construction industry in these regions.

In addition to expanding the capacity of existing companies and site expansions, depending on demand and the future potential of timber construction, another possibility is the active merging of individual companies into working groups in order to be able to work on larger projects jointly, so that at the same time there is an exchange of information and experience. Political support would also be conceivable. However, this must be country-specific and therefore depends on the interests of the individual governments. In addition, targeted promotion of the timber construction industry can also create resistance from the already existing and influential construction lobbies that are active in the masonry and concrete industry.

3.2.3 Standard solutions

Components must meet various performance criteria. In addition to fire protection requirements, these include sound insulation, stability and thermal insulation. A functional layer in the component can also take over several functions.

Connections are the greatest weakness, as they are more expensive to construct than the surface. The individual functional layers of the components must be connected without losing their performance characteristics. For this reason, the risk of incorrect design in planning and risk of assembly errors in execution are higher.

In timber construction, there are a multitude of possibilities for the formation of these connections. On the one hand, this is due to the different construction methods used in timber construction (timber frame construction, solid timber construction, post and beam constructions, etc.) and the associated connection details. On the other hand, there are also regional differences due to the building culture with regard to the spread of the individual construction methods (Hurmekoski et al. 2015).

If the decision makers lack the necessary knowledge and experience to plan the connection details, this can lead to errors due to the high complexity, which can reduce the durability of the building and result in increased costs due to subsequent improvements.

One way to facilitate the planning of connections and to provide appropriate evidence is to use component catalogues. In addition to component elements, these can contain exemplary guiding details which the planners can refer to and, if necessary, adapt to the respective situation.

Another possibility is the development and collection of project-related component catalogues. These include the details and component structures of already completed projects, so that a traceability of practical connections is given. In order to get access as easy as possible, it is necessary to develop a central collection point where the catalogues for standard solutions can be stored and accessed.

The online platform dataholz.eu is mentioned as an example. It contains information on the building materials used, component elements and joint details. In addition to the building components, characteristic values for their physical behaviour (fire resistance, sound insulation and thermal insulation) and their ecological impact are provided. The component data sheets can be used in Germany and Austria as a verification method for authorities, since the characteristic values are determined by accredited test institutes.

Even if the given documents cannot be used as component verification in other countries, they are helpful as information and planning aids for standard bodies. On the basis of details and illustrations of the assembly sequence, the applicability is thus more easily illustrated. Due to the access to this platform, a greater range can also be achieved.

Country-specific guidelines for timber construction projects are also a way of simplifying the implementation of projects and making planning easier.

In a life cycle analysis of a building, all life phases are considered. These lead from the extraction of raw materials and manufacture, through the construction and operation of the building, to its later dismantling. Recyclability is another important issue in the design and use of materials, connections and technical structures.

The costs of demolishing buildings may seem rather irrelevant, as this will only happen at a much later date. The normal lifetime of a newly constructed building in Sweden is normally set at 50-70 years, in Germany for example it is 50 years. In other markets, however, buildings are valued as consumables with an average lifetime of 26 years (Japan) (Bengtsson 2009). Here the costs of demolition and disposal of the materials are more important.

Compared with traditional construction methods, timber construction has the disadvantage that the structures and connection details are very complex (Teischinger 2016). For this reason, sorting can be difficult and costly during demolition work. The removal of panel materials fixed with screws can cause considerable additional costs due to the time and effort required.

Therefore, even with regard to standard solutions, it is necessary that the constructions are as homogeneous as possible and that each layer can be easily detached from the substrate without much additional effort. System solutions and connections are also required that allow individual components to be reused, thus extending their service life. Further research is needed in this area, as wood components usually consist of several layers that fulfil different functions. Also in terms of fire protection, it is therefore useful to consider the admissibility of exposed wood surfaces in order to reduce the number of layers, if appropriate countermeasures are developed and applied, so that no increased risk for users arises. For this reason, further research must be carried out to improve the issue addressed. This requires the financial support from politicians and interest groups.

In addition to these measures, the countries must pursue strict logistics for recovered wood for the wood-based materials industry and the energy sector in order to keep the materials used in a closed cycle.

3.2.4 Fire safety

Fire safety concerns are one of the most frequently cited reasons in the works analysed and thus one of the biggest obstacles to the spread of timber construction. In (O`Connor 2006) the use of timber construction methods by architects and engineers for non-residential buildings is investigated. In this context, the building code is regarded as one of the biggest obstacles for the use of wood in the building sector with regard to fire protection properties.

Due to the combustible character of wood as a building material, its active use in buildings is restricted by building regulations in most countries. This concerns especially large and tall buildings. Building codes and fire codes reflect the minimum safety requirements for the construction of buildings in a country (Wolski et al. 2000).

Although the main objectives of the individual building codes are similar in their requirements, there are differences in design and formulation (Visscher et al. 2003). This may be due to the emergence of building codes that are determined by government policy. The development was influenced by national events such as energy crises, city fires or building collapses, but also by industrial lobbying and research.

The main differences in the restrictions on timber construction lie in the permissible number of storeys and in the visible wooden surfaces of interior and exterior building components (Östman et al. 2010). However, there are also countries that do not have specific regulations or where the permissible number of storeys is limited (see Annex A.2). Furthermore, there are differences in the evaluation of fire protection systems. Some countries evaluate the use of sprinkler systems for early firefighting positively and allow the use of wood as an example of a visible surface. Other countries, on the other hand, do not allow any simplifications for timber construction despite sprinkler systems or do not take these technical possibilities into consideration.

Due to the principle of subsidiarity, the individual member states can set different requirements for the performance of building components and building products in their respective building codes, so that no European requirements exist (Duhaut 2015). The basis for the national requirements are European, harmonized product standards, which define individual tests to be carried out. If no harmonized standards currently exist, national specifications are still valid. However, this can lead to restrictions, as the safety levels for fire protection differ from country to country. Therefore the link between national requirements and the performance of building products is often unclear (Östman 2002) The CE-marking of building products is also covered by other possibilities. In this context, reference is made to chapter 2.4 Political barriers. Despite the introduction of harmonized systems for the classification of the fire performance of building materials and building products, there are still major differences in the description of fire safety strategies, building classification or the description of building components (Visscher et al. 2003).

In general, it can be said that a country that traditionally has more experience in timber construction has fewer restrictions by building codes than other countries. With regard to an increased use of wood in buildings, adequate fire safety is a key requirement.

The different requirements can mean an increased planning effort for building projects of companies in another country, because first the necessary conditions and regulations regarding fire safety for the building have to be determined. The table in Appendix A.2 can provide assistance or an overview here. However, it should be noted that due to continuous adjustments and changes in the building regulations of the individual countries, a general validity is not given and the table would have to be constantly adjusted accordingly.

A simplification in this sense would be a harmonization of the building regulations, which, however, seems impossible in the near future due to the different individual interests and environmental conditions of the individual countries.

With a better understanding and knowledge of new technologies, new measurement tools, experimental and full scale testing and new types of risk assessment, it is possible to mitigate previous concerns and restrictions regarding timber construction. For this purpose, in addition to construction measures, the possibility of combining them with technical instruments (sprinkler systems, smoke detection systems, well-equipped fire brigades) must be considered, as these can make the safe use of wood possible.

In this respect, the exchange of knowledge and experience between the individual countries appears to be useful, firstly to dissipate concerns about fire safety and to disseminate specialist knowledge to countries without wood building traditions, and secondly to identify areas in which research is still needed. It is also important to avoid overlapping or multiple work in a single research area and thus to use the available funds and resources as efficiently as possible.

In order to enforce facilitations for timber construction in building codes, effective communication between research, the responsible authorities and the public is also necessary to improve the understanding of fire safety in timber buildings and to promote it (Gerard et al. 2013).

3.3 Economic barriers

3.3.1 Availability and supply chain

Countries without large forest areas naturally have little or no wood building tradition or culture and the associated know-how, which is why the use of wood does not play a major role in their building industry even today. Therefore, the corresponding building regulations do not explicitly consider wood building methods or contain major hurdles (Hansen et al. 2014).

In the survey carried out within the framework of the project, it was found that countries without a timber construction tradition often do not have a forestry value chain. Due to the lack of resources, the necessary production facilities for the manufacture of timber construction products are also lacking.

Figure 3-5 shows the share of forest area in the respective national area of the European member states and members of EEA and EFTA. It can be seen that there is a great imbalance in the available forest areas. Above all Norway, Sweden, Finland and the Baltic States have comparatively extremely high tree populations.

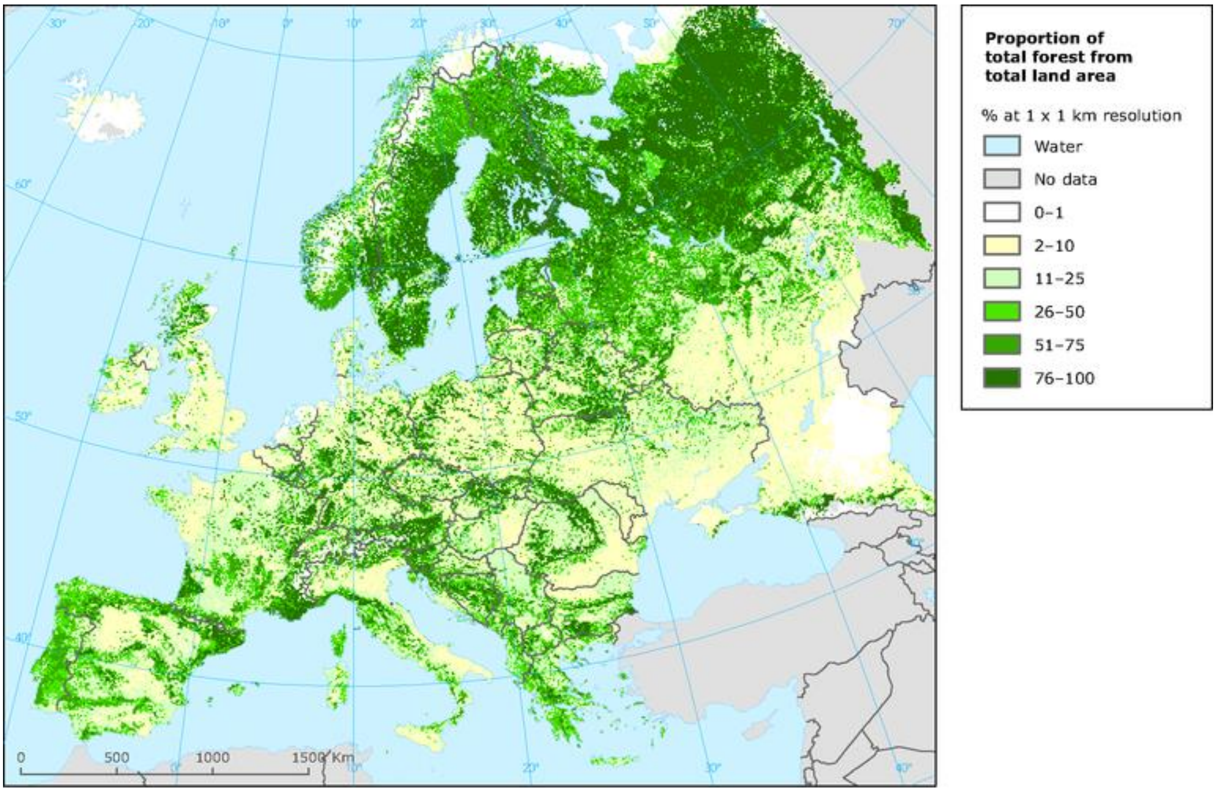

Figure 3-5: Proportion of total forest from land area of Europe (European Forest Institute (EFI) 2009)

In order to obtain a comparison of the forest area actually used, the wood supply area of the individual countries is compared on the basis of the data from Eurostat (see Figure 3-6). For the sake of clarity and ease of presentation, only the 15 largest forest areas are shown. A diagram with all EU/EEA/EFTA member states is provided in Annex A.3. The diagram shows the values for the years 1990 and 2015. In addition, the development of forest and wood supply area over the years 1990 to 2015 is given in percent.

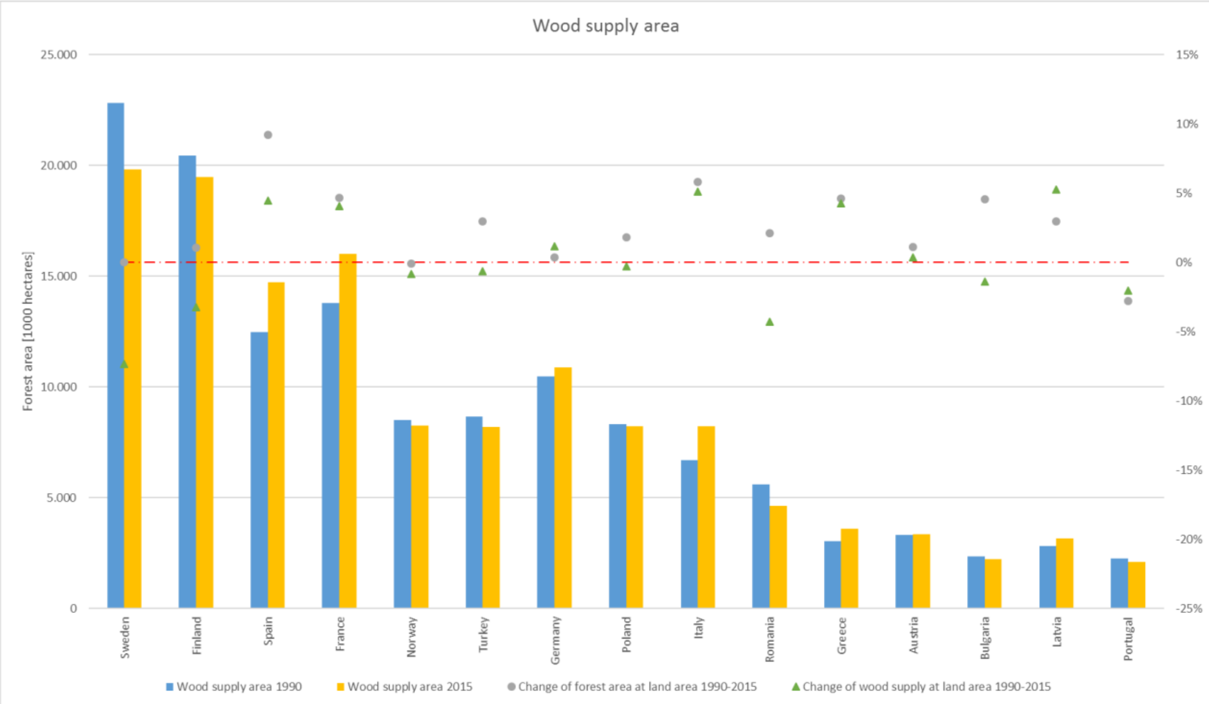

Figure 3-6: Wood supply area of the 15 member states of the EU/EEA/EFTA with the highest forest area

It can be seen that for a large part of the European countries the proportion of forest area in relation to the total area has increased, which runs counter to the general trend of deforestation in the 20th and 21st centuries. In contrast, the share of wood supply forests in the total forest area is decreasing in the Nordic countries Sweden, Finland and Norway. In Spain, France and Germany, on the other hand, there is an increase.

The data shows that there is still potential in the use of wood due to the growth of trees and that further capacities would be available to meet an increased demand.

Climate change poses a problem for the forest value chain. This is causing uncertainty with regard to future security of supply (Winter 2016). Examples are the increasing spread of wood pests (bark beetles, non-native fungi, etc.) and the change in the composition of wood stocks (less precipitation, temperature stress of trees, etc.). The risk of forest fire also increases due to excessively dry summers, which can lead to the loss of large areas of forest. Another factor is the decreasing wood quality due to the faster growth of trees (Sikora 2018). Based on the high requirements for construction timber and timber products for civil engineering structures, only a specific proportion of the total raw timber quantity can be used for construction purposes. Due to the diversity of the raw wood, different utilisation paths including pulp and paper wood and the chemical and energy sector are necessary to utilise the greatest possible potential.

Different wood process chains with increasing demand compete for the supply of raw material. Despite this competition it must be possible to provide a selective and increasing proportion of suitable roundwood for the conversion process for building components. For this reason, a sustainable and secure supply of raw materials must be ensured for the increased use of wood in the construction industry and also for energy recovery as a substitute for fossil fuels. In order to promote the acceptance of wood as a sustainable building material, high standards should therefore be set for the compatibility of forest management, nature conservation and climate protection in wood production and processing.

The following figure 3-7 shows the amount of engineered wood produced in the 15 European countries with the largest forest areas for the year 2015. However, no data for CLT have been used in this figure, as this has not yet been comprehensively recorded by Eurostat in recent years. In addition to the engineered wood, the share of forest area in the total area of a country and the share of commercial forest area in the forest area are also shown.

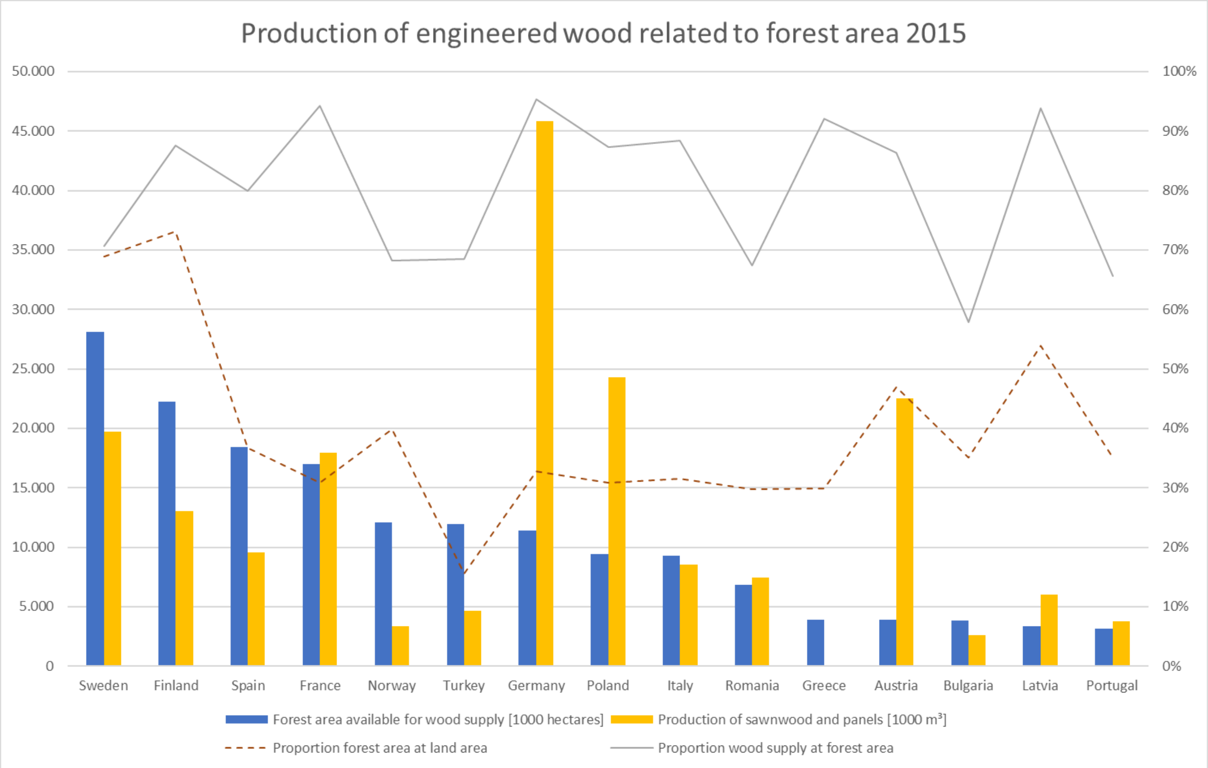

Figure 3-7: Production of engineered wood depending on forest area 2015

It can be seen that the countries with the largest areas of commercial forests are not at the same time the largest producers of engineered wood. Here Germany, followed by Poland and Austria, are the largest producers. Poland has a large share of sawnwood, particleboards and plywood. It should be mentioned that not all sawnwood is used in the construction sector, but also in other secondary processing such as packaging, furniture production, joinery etc. (Baudin 2003). It is assumed, however, that 2/3 of the sawnwood produced is used for construction (Hurmekoski et al. 2014). The Scandinavian countries have lower production rates in relation to their forest area.

However, this situation changes when production figures are related to the population of a country, as the Scandinavian countries, for example, have a very low population density compared to their land area (see Figure 3-8).

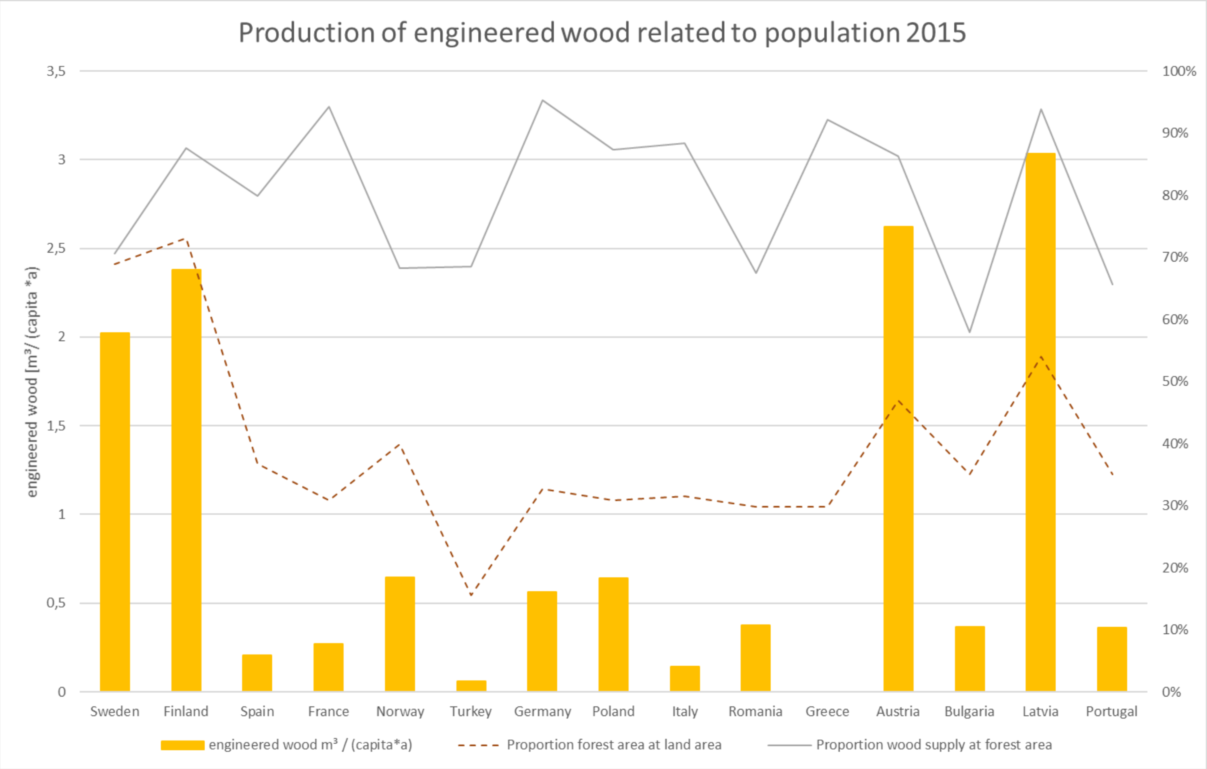

Figure 3-8: Production of engineered wood related to the population (per capita) in 2015

Here it is clearly visible that the countries Sweden and Finland as well as Austria and Latvia have a high production rate of engineered wood in relation to the population. It is also noticeable that these countries have a comparatively high share of commercial forests in the total forest area.

The large regional differences in available forest resources also result in differences in the markets for multi-storey timber construction. Especially in countries where the market share of timber in the single-family house sector is already high, a penetration of the market with multi-storey timber construction is more successful. (Hurmekoski et al. 2014)

Based on the growth of timber, the use of coniferous timber per inhabitant and GDP, (Hurmekoski et al. 2015) divided the European member states into four groups (see Table 3-2) in order to determine the market potential and the possibility of market penetration for multi-storey timber construction. The 15 European countries with the most multi-storey timber buildings built between 2000 and 2012, which also represent the largest markets, are shown. For the other countries, it can be assumed that, due to the insignificant forestry, there is no relevant industry to ensure their own supply of the necessary timber products. At the same time, it is unlikely that the necessary interest and knowledge will be available to introduce their own production facilities and supply chains. For this reason it is unlikely that multi-storey timber construction will become established in these countries.

Table 3-2: Country groups of the largest multi-storey construction markets (Hurmekoski et al. 2015)

Region	Northern Europe	Central Europe and the UK	Western Europe	Southern and Eastern Europe
Market penetration potential by 2030	High	Intermediate	Low to intermediate	Low
Rate of prefabrication	High to intermediate	High to intermediate	Low to intermediate	Low
Countries/regions	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

All in all, it can be said that in regions where timber construction in the multi-storey area already has a larger share, there is a need for sustainable forestry in order to be able to meet additional demand and ensure a secure supply of raw materials in the future. In this context, cascade use (re-use, recycling, etc.) should also be mentioned in order to obtain additional sources of use.

Larger market shares with regard to multi-storey timber construction are also likely in countries with large areas of commercial forests and a larger share of timber construction in the single-family house sector, which corresponds to the Nordic countries Norway, Sweden and Finland, Central Europe and the UK, as these countries have the necessary knowledge and experience as well as sufficient resources and production facilities.

The likelihood of bringing about major changes in regions where wood has traditionally played a minor role in the construction sector is estimated to be low. In order to reach other regions where timber construction is not present in terms of building culture, the first step is to ensure the establishment of supply chains, the accumulation of assembly and engineering knowledge and marketing and distribution models. Public interest must also be created to establish a potential market. However, this requires influential stakeholders to promote the spread of timber construction.

3.3.2 Planning

Strong competition, the declining labour force in European countries and, above all, the need for affordable housing are driving the improvement of productivity in the construction sector. One way of doing this is the industrial prefabrication of components and modules (DTI 2009).

A great potential of timber construction lies in its high degree of prefabrication compared to traditional construction methods. This results in many advantages (Mahapatra et al. 2012) (Jonsson 2009):

- Efficient moisture, quality and cost control
- Less noise pollution in production
- Increased safety for workers
- Installation indoors, in a dry and clean environment
- Cost savings through material reduction and shortened construction time
- Less construction waste

Figure 3-9 below shows an example of the shortened construction time by a high degree of prefabrication.

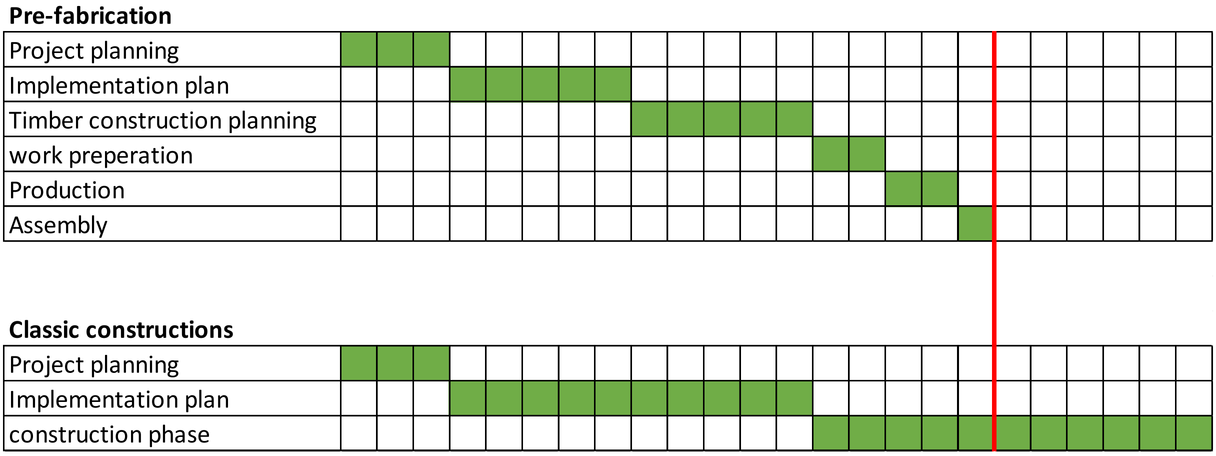

Figure 3-9: Possible time planning, production and assembly sequence in weeks for a medium-sized timber construction in comparison to the conventional procedure as for example in masonry or concrete construction (Kolb 2007)

However, good planning and coordination of the trades are necessary for a smooth and regulated process. If this is not available, it can be assumed that the potential of the short construction period cannot be fully exploited.

Basically, three problems can be distinguished, which cause increased costs for timber construction:

- Assembly problems on the construction site
- Planning error
- Difficulties with the timing

Errors in the planning of the construction process, incorrect delivery dates or poor calculation of the completion of crafts can lead to considerable delays and costly rescheduling. Frequently mentioned problems are, according to (Gosselin et al. 2017), a longer lasting design phase as well as manufacturing and delivery problems. Due to these, the time schedule has to be restructured, which can lead to new delays.

Since even during the construction phase changes in timber construction are more difficult to make compared to steel or concrete construction, increased attention must be paid to the planning phase (Gosselin et al. 2017).

Poor communication between the trades can also lead to delays, since many stakeholders are involved in timber construction, but a large part of the planning must be conceptualized in the draft, since subsequent changes during the construction phase are difficult and can only be implemented with increased additional expenditure. This applies in particular to fire protection and building services engineering planning, as the supporting structure and components are directly affected.

For this reason, early cooperation between central players, including planners and manufacturers, is necessary to bring together central expertise in timber construction and assembly. The interface between the production plant, suppliers and construction site is particularly important for a smooth construction process. In addition, in timber construction, the timeline in the construction process shifts from execution to planning. Here it makes sense to include sufficient time for the planning process, as this can prevent high costs in the event of reworking on the construction site, which means that in case of doubt the entire potential is not fully exploited. It is also necessary to involve the planners and trades involved at an early stage in order to prevent overlaps and conflicts of interest. A further advantage of this is the individual exchange of experience between the persons involved. Especially wood product manufacturers should be involved at an early stage in order to optimise the necessary components and elements and, if necessary, to use a high degree of standardised production lines, which can lead to further cost savings (Ruuska und Häkkinen 2016). The use of standardized structural solutions, in addition to leaner production processes, also leads to a lower risk of planning and execution errors and a faster planning phase. In this sense, the extension of the platform dataholz.eu would be a conceivable option to provide planners with the execution and assembly of components and their connections with the respective performance level.

The problem of complex planning mainly affects countries with little experience in timber construction. Here, probably neither the necessary infrastructure for the production of the building components nor the planning knowledge or practical experience is available to guarantee a smooth construction process. The scope of the design work is also increased for timber constructions. Connections in particular require a higher degree of detail in planning. Therefore, the amount of work is additionally increased by the fact that the number of detailed drawings in timber construction increases.

In order to deal with the high complexity and the associated uncertainties of planners, an exchange of information and experience is necessary. This can be achieved by means of handbooks that give recommendations for action and describe problems and their solutions in previous projects (Sardén Ylva 2005). Furthermore, standardised connections and concepts would be another possibility to reduce and simplify the planning effort accordingly.

Building Information Modeling Programs (BIM) are another way to simplify planning. In addition to considering the purely physical properties of the building, BIM creates a digital model that accompanies the building throughout its entire life cycle. BIM-based design thus enables leaner processes. Furthermore, it enables effective cross-checks of structural and HVAC models. Here, a distinction can be made between different types of structure (Horx-Strathern et al. 2017):

- 3D BIM: Three-dimensional representation of the building project
- 4D BIM: Integration of the construction scheduling into the 3D model
- 5D BIM: Cost planning and cost management of construction work or the whole project
- 6D BIM: Information for the maintenance and operation of the building

At present, BIM software is largely designed for the use of steel and concrete structures and does not sufficiently consider the modelling of wooden structures (Nawari 2012). For this reason, further research and development on these tools is needed to make it easier to compare them with traditional construction methods and to work out the positive effects of wood in terms of CO_2 storage and energy consumption during production.

3.3.3 Insurance

The use of large quantities of combustible materials, as is the case with multi-storey buildings in timber construction, can increase the severity of a fire due to the additional immobile fire loads. In addition, the uncertainties regarding the durability and damage of wood compared to, for example, flooding or damage after fire-fighting operations and the associated costs can lead to increased policies (Gallagher 2018).

From an insurer's point of view, the amount of the insurance policy is determined taking into account the building materials used. Due to the combustibility it seems logical, therefore, if the risk of a claim is estimated to be higher than with traditional construction methods and the insurance policy increases accordingly. In addition, the insurance industry usually refers to historical data when assessing and determining the insurance policy. As a result, the probability of higher losses appears greater for the insurer than with traditional construction methods (Kremer und Symmons 2016). As many timber construction systems are relatively "new" developments (e.g. CLT), it is likely that higher insurance premiums will be charged due to timber classification. This is the case in all countries with little experience in this field, as there is a lack of new valuation principles due to a lack of examples built.

To avoid this cost problem, it is necessary to change the perception of insurance companies for projects in multi-storey timber construction. This can be done through information campaigns organised by interest groups. In these campaigns, insurers can be sensitised to the risk issue. It is important that experts discuss the latest developments in the timber construction industry and show that suitable fire protection measures do not increase the fire risk compared to traditional construction methods and that durability can be guaranteed.

Furthermore, the financial forecast models of the insurance companies must be revised so that timber construction no longer leads to increased insurance policies. This requires the provision and collection of available data on buildings already constructed. To this end, data exchange programs must be developed at European level. Especially countries with little experience can benefit from this since building costs will be reduced.

This requires better networking of the players in order to facilitate the desired flow of data and information. International exchange is also conceivable in order to reach a larger group of stakeholders and, if necessary, to open up new markets outside the EU.

3.4 Political barriers

3.4.1 Standards

One of the objectives of the European Union is to trade freely within the borders between the individual EU countries. The process for achieving this goal is defined as harmonization. Construction products are covered by Regulation 305/2011, known as the Construction Product Regulation (CPR). The CPR focuses on the harmonization of standards and test methods for various construction products. Products that pass the prescribed tests may be freely traded in the EU market under indication of a declaration of performance. For construction products that are not yet included in the CPR, there is the possibility of an ETA (European Technical Approval) in order to obtain the CE mark.

Many construction products are described by harmonized standards of the European Union under the CPR, which came into force in 2011 and replaced the CPD (Construction Product didrective). These standards are adopted by all EU/EEA/EFTA countries and are valid throughout Europe. Due to the existing standards, there is a uniform basis for design and requirements for planners. However, as research work is constantly being carried out and new construction products are being developed, it is possible that the existing design and product standards do not reflect the current state of the art and cover all products intended for the market. Besides uncertainties in planning, this can lead to additional expenses for planners, as additional verification methods have to be provided. This applies in particular to timber construction, as a large number of new building products and developments have been created in recent years. In the absence of standardisation, companies usually provide their own design data in order to be able to sell their products. However, this results in a wide range on the market, which makes it difficult for the planner to have a clear overview, since the measurements have to be carried out product-related (Ebert et al. 2017). Furthermore, tests and verifications are necessary to prove the required safety level, which leads to additional work and costs for the manufacturer.

Examples of non-existing design rules for timber products in the current version of (DIN EN 1995-1-1) (Eurocode 5 -EC5) are reinforcements, cross laminated timber and wood-concrete composite structures, which are, however, included in the new version of EC 5. In the absence of harmonized European design rules, national design approaches are used, which make planning across countries more difficult because no consistent method is used.

Another example are adhesives for the use in load-bearing timber components. The adhesive systems are classified according to (DIN EN 301), in the temperature steps 50 °C, 70 °C and 90 °C. This enables the design of the building products used. However, this does not take into account the softening of the adhesive bond at higher temperatures, as occurs in case of fire. The present methods do not cover such performance and even if adhesives are allowed for timber structures, they still have different properties and some of them very different thermal stability. This behaviour was revealed and was defined as fall-off of glued lamellas and is discussed by researchers, community and insurance companies as possible danger in case of high timber buildings. It is still not known how different adhesives perform in fire because there are no methods to test it. Therefore it is of great importance to cover such gaps of knowledge and clear up what the risks are and sort out which methods could possibly be used to document the products' behaviour in fire.

In (DIN EN 1995-1-2) (EC 5) it is mentioned that "Adhesives for construction purposes shall be capable of producing joints that provide sufficient strength and durability of the bonded joint for the relevant fire resistance period". However, no further specific details are given. In addition, the adhesive tests are categorised by different standards. Adhesives that belong to the group of phenols and amino plastics must meet the requirements of (DIN EN 301). 1-component polyurethane adhesives (1-component PUR) are tested according to (DIN EN 15425), whereas emulsion polymerised isocyanates (EPI) are treated in (DIN EN 16254).

Casein adhesives according to (EN 12436:2001), on the other hand, may not be used for example in Germany although a harmonized test standard exists, due to insufficient quality requirements and the addition of preservatives. With regard to the strength development at high temperatures, the bonded test specimens are constantly loaded at a maximum of 90°C for two weeks. This can inhibit the spread of timber construction in so far as, there are public and building regulation concerns about fire protection due to the combustibility of wood. If the performance of certain adhesives and joints cannot be exactly estimated with the normative design methods, this can lead to rejection of such constructions and further spread.

Further research based on experiments and simulations is therefore necessary to determine missing limit values. On the basis of these, further design approaches can be derived so that the safety level is increased and any gaps in the design procedures can be closed. It is also necessary to develop new test methods to enable the validation for material-specific behaviour.

In this respect, it is important to keep standards up to date in order to achieve greater clarity and at the same time reduce the risks for planners. Lack of information makes detailed planning and the development of standardised solutions more difficult. The responsible European standardisation committees are made up of representatives from different countries who represent different interests in terms of building culture. For this reason, the development of European standards is extremely time-consuming. At the same time, compromises are necessary in order to reach agreement on specific design procedures, limit values, test methods, etc. Due to the long planning and development of the standards, a consideration of all relevant building products and techniques is not possible (Dederich 2013). Due to the long process leading to the final version of a standard, newly developed products are often not considered.

Standards for construction products are often complex and often not very practical. Excessively extensive design standards are to be found, as are construction product standards which do not deal with essential requirements for the products, or deal with them only inadequately or even contradictorily. The position and needs of all stakeholders are not always taken into account during the harmonization process (Nwaogu et al. 2015). For this reason, and because of the frequent lack of information on non-regulated construction products, the acceptance for the use of the EC5 may decrease.

In order to develop suitable standards for building with wood, it is necessary to facilitate the participation of timber construction practitioners in the development of standards. Overall standards and norms should be reviewed and made more coherent (Dederich 2013).

The EU member states have the possibility to determine important Nationally Determined Parameters (NDP) independently of the proposed values. This means that the responsibility for maintaining the safety level to be achieved remains with the individual countries. As a result, no uniform regulations apply within the European Union. The aim of European harmonized product standards is to replace national product standards. For this reason, a high level of acceptance for design using the Eurocodes as well as the reduction of NDPs is an objective of the ongoing harmonization. In EC5 59% of the recommended values of the NDPs are accepted. However, the values differ depending on the country. Central European countries have a lower acceptance rate than Eastern European countries or countries with small areas. This may be due to the fact that these countries want to maintain their traditional national values, as the recommended values do not reflect them sufficiently. For fire design (DIN EN 1995-1-2), a significantly higher acceptance rate of 80% is achieved for the NDPs with recommended values than for cold design (DIN EN 1995-1-1). However, there are also large national variations in the degree of acceptance of the NDPs, which means that national regulations have a large influence on fire design (Sousa et al. 2019). Based on these values, it can be said that EC5 has a high level of harmonization, especially for fire design, as many countries have accepted the proposed NDPs. However, for the second generation of the Eurocodes, a revision of the cold design is necessary to reduce the obstacles resulting from national practices.

3.4.2 ETA

The Regulation (EU) No. 305/2011-Construction Products Regulation regulates the placing on the market of construction products. It itself does not contain any technical specifications, but only sets seven basic requirements, derived from the building regulations of the member states, for buildings that must be fulfilled (European Parliament 2011):

- Mechanical strength and stability
- Fire protection
- Hygiene, health and environmental protection
- Security and accessibility in use
- Sound insulation
- Energy saving and thermal insulation
- Sustainable use of natural resources

These form the basis for harmonized technical specifications (standards), which provide the essential characteristics required of construction products. If the construction product is covered by a corresponding technical specification, the manufacturer must draw up a declaration of performance (DoP). By means of this, the manufacturer declares that the declared performances are in conformity with the essential characteristics of the standard. The declaration of performance does not have to cover all the characteristics included in the standard, but at least one. Characteristics that are not determined/measured can be marked "npd" (no performance determined). As a further step, a visible CE marking must be affixed (Kuplich und Schlesinger 2018).

With the introduction of the CPR, it is no longer permitted to impose further-reaching national building code requirements on harmonized building products. However, as the national building regulations may have different rules, it is possible that the necessary technical specifications of construction products cannot reflect all of these properties. The disadvantage here is that not all features of a harmonized technical specification need to be included in the declaration of performance. This may result in certain requirements not being identified by the declaration of performance. Although this makes it possible to place and trade the building product on the European market, it does not provide a completeness of the services to be provided which are necessary for a construction work according to the basic requirements (Kuplich und Schlesinger 2018). In summary, the problem for planners is that a building product with CE marking does not necessarily fulfil the requirements placed on the construction work.

In order to be able to demonstrate that the requirements of the Construction Products Directive are fulfilled by the construction products, the designer has to define all necessary performance characteristics covered by the declarations of performance of the construction products.

The same problem also exists for European usability certificates, which are used if there is no harmonized standard for a construction product or if there is a significant deviation from the standard, but the manufacturer wants to use the product within the EU. A European Technical Assessment (ETA) enables a CE marking of a construction product, although it is not, or only partially, covered by a harmonized standard. This makes it possible to trade this product within the European internal market. An ETA is issued on the basis of a European Assessment Document (EAD), which contains the necessary assessment procedures and, like a harmonized standard, represents a harmonized technical specification.

After issuing an ETA, the manufacturer of the construction product is obliged to issue a corresponding declaration of performance and to mark the product with a CE marking.

As with a harmonized standard, the ETA offers the possibility to be adapted to national construction requirements in order to enable the use of the construction product in this country. However, this does not correspond to the actual idea of harmonizing the use of construction products throughout the European Union.

All in all, an ETA offers the possibility to market a construction product in Europe which is not, or only partially, covered by harmonized standards, or to describe it specifically to country-specific performance requirement. However, since nationally different building codes apply, which may contain different performance criteria, it is difficult to cover all factors in the declaration of performance.

The problem arising from the different national requirements is hardly solvable. Due to the contractual distribution of competences between the EU and the Member States (subsidiarity principle), regulated in the Treaty on European Union (TEU) and the Treaty on the Functioning of the European Union (TFEU), harmonization measures must not go beyond the objective of a functioning internal market. Accordingly, the Construction Products Regulation mainly regulates the marketing of building products in the EU internal market. However, the EU is not entitled to harmonize construction requirements. The protection objectives and the level of protection are set by the respective member state and therefore differ. However, climatic, geographical, construction-cultural and traditional differences also play a role here, making harmonization difficult (Abend 2018).

Although harmonizing the building requirements of the individual Member States would make it easier to use nationally established and new building products, especially in relation to timber building products, this is not legally feasible under the current conditions. Furthermore, there are nationally different boundary conditions, which is why differentiated requirements will continue to exist.

It is more appropriate to implement "requirements documents" at European level. In this document, which is independent of manufacturers, all national construction requirements for a construction product with a specific intended use are summarised. Thus, the document lists all performance characteristics from European harmonized technical specifications, nationally required properties and national rules of use. The document serves as a basis for planning and ensures that the building product complies with the individual national requirements (Kuplich und Schlesinger 2018). In order to extend this concept to the European level, however, a transnational cooperation of different stakeholders is also necessary, which makes coordination and feasibility via the national level more difficult.

A further problem in the absence of harmonized technical specifications (standards) for new construction products is the time needed to prepare an ETA, as a new EAD must first be developed in order to assess the construction product-specific properties. This generates additional costs for the manufacturer and requires a longer period of time until the product can be marketed.

This problem is rather unavoidable as test methods for innovative products do not exist or only partially exist. Due to the safety aspect, it is therefore advisable to define suitable test conditions, even if this can lead to delays and increased additional costs for the manufacturer.

However, the survey carried out within the project states that the procedure for obtaining a technical assessment document is considered rather complex. This conclusion is also confirmed by (Nwaogu et al. 2015). Here, the introduction of the CPR is analysed together with the associated objectives and their actual impact (see Figure 3-10).

Table 7-1: Summary of findings				
Aspect	Objectives achieved[1]			
	Simplification	Clarification	Credibility	Free movement
Definitions		✓		
Obligations of economic operators		✓		
Declaration of performance	✓ X	✓		
CE marking	✓ X	✓	✓	X
Simplified procedures for products not (fully) covered by a hEN (EADs/ETAs)	X	X	X	
PCPC	X			X
hENs		✓	X	X
AVCP		✓ X	✓ X	
Levels and classes of performance	X			X
TABs			✓ X	
Notified bodies			✓	
Notifying authorities			✓	
Simplified testing procedures	✓ X			
Information campaigns		✓		
Market surveillance			X	

[1] Key:

✓	Objective achieved
✓ X	Objective partly achieved
X	Objective not achieved
	Not applicable

Figure 3-10 Effectiveness of CPR`s objectives (Nwaogu et al. 2015)

It is noted that a simplification for product approvals which are not or only partially covered by European harmonized standards is not achieved. As the route to CE marking is voluntary and the industry perceives it as complex, it may choose to certify innovative wood products with national marks, which can be an obstacle to trade and dissemination of these products. However, simplification can only be achieved through a future revision of the CPR. On the basis of the present report, it can be assumed that the criticised points will be addressed and that proposals for solutions or improvements will already be developed.

3.4.3 Building Regulation

Classification methods and the performance of fire tests are harmonized at European level, but the requirements under building law are determined nationally. This means that technical rules in the form of the harmonized standards exist at European level, but the fire protection requirements for buildings are determined by national regulations in the form of building codes and directives and thus at political level, and therefore differ.

3.4.3.1 Formulation and structure

Building codes define the minimum standard for buildings to ensure safe use. For this purpose, requirements are set for certain subject areas, which must be fulfilled by the building components used. However, there are differences in the individual member states of the EU in terms of formulation, structure, responsibility, etc. (Branco Pedro et al. 2010).

In general, building regulations can be divided into three different formulations:

- Functional
- Performance based
- Prescriptive

In the case of functional requirements, only the main objectives are prescribed and no information is given on the level of performance to be achieved, methods of detection, materials to be used or possible solutions. Performance-based building codes define the level of performance to be achieved. At the same time, investigation procedures are specified (Östman et al. 2017). A prescriptive approach, on the other hand, requires a specific construction solution instead of the performance requirement. The individual states of the European Union do not have a uniform formulation of their building codes (see table 3-3).

Table 3-3: Formulation of European building regulations (Branco Pedro et al. 2010)

	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	United Kingdom
Functional	□															■								■			■
Performance	■	■	■	□	■	■		■	■	■			■	■	■	■	□	□	■		■	■		■	■	■	
Prescriptive	■	■	■	■					■					■	■	■	■	■			■			■			
No information							■				■	■								■			■				

Due to the formulation, disadvantages in the application can arise for timber construction. For example, in a prescriptive approach, the requirements can easily be met and verified and a simple third party inspection is possible. However, with fixed and accepted solutions of the prescriptive approach, such as dimensions or specific materials, it is not possible to use newly developed products or certain materials such as wood as a load-bearing structure, because the information provided limits the use of these products, although they would satisfy design requirements. Thus, the building code would have to be continuously adapted if a new solution, proven to meet the requirement and accepted by the general public, were to come onto the market.

Another problem with prescriptive formulations is that no performance level to be met is specified. For this reason, it is difficult to demonstrate that another design will provide the same level of performance as the solutions specified. This can result in high costs in two ways. Firstly, in proving that the performance level not specified in the building regulations can be met by the new proposal. Secondly, in using the specified solutions, as it may not be possible to take into account cheaper solutions or processes, although these would not reduce the level of safety.

For the individual states with prescriptively formulated building regulations, there are usually different approaches to solutions for, for example, component structures made of wood with fire protection requirements. Here it is often difficult to establish an equivalence of these. For this purpose it would again have to be proven that the performance level of one country corresponds to the performance requirements in another country. This can limit the trade of construction products and market penetration within the EU (Foliente 2000).

With regard to fire protection requirements, which limit timber construction to certain areas of application (building height, cladding, etc.), the performance-based approach offers a way to facilitate innovation. As a result, there are no longer any restrictions for certain materials as e.g. timber and fair competition between construction types is created. The safety risk is also not increased, as proposed solutions require the achievement of the prescribed performance. In this sense, a performance-based approach should be sought for all building codes.

In addition, the building regulations can be organized differently. It is possible that there is only one main document containing the technical requirements to be fulfilled. There may also be a group of documents that contain the technical building regulations and are organized according to the technical requirements. A third option is the existence of separate legal documents describing the technical building regulations for specific requirements and building types (Branco Pedro et al. 2010). Due to the different structures and layouts of the documents, it can be difficult for actors who are not familiar with the building law to understand certain rules and limits. As a result, it can be more difficult to familiarize oneself with the legal framework and errors can easily occur if the background of individual requirements is not understood.

Furthermore, there are national differences in terms of wording and background information in the documents. In the building regulations, there may be comments on recent changes and descriptions. But the principles on which the requirements are based are usually not explained. Independent instructions are usually necessary. An exception are the English Approved Documents, which explain the background behind the regulations already in these documents (Visscher et al. 2003). The Norwegian guidelines to the building regulations also give some explanation about the background of the regulations. The regulations and guidelines are presented together in a web version.

This lack of clarity makes understanding, familiarization and application difficult for inexperienced planners. In this respect, a harmonization of building regulations at European level would be desirable, but this is considered impossible due to the individual interests of the individual member states and the underlying principle of subsidiarity. However, centralisation and standardisation of the structure and content of the documents would be desirable in order to reduce the additional workload for construction workers working on a supra-regional basis.

In order to facilitate application and understanding, it is conceivable to include references to the individual verification methods in a performance-based approach. The references to the relevant standards simplify the planning process, as reference is made to the design, testing and material standards that must be achieved in order to meet the necessary requirements. A clearer structure would also simplify the tracking of requirements down to the most detailed versions. An explanation of how to use the different documents for a building design would also improve the understanding of its structure.

3.4.3.2 Additional requirements

There are many different requirements, regulations and restrictions that must be taken into account when constructing buildings. The use of wood is usually restricted by fire protection regulations. However, these are not uniform at European level. As a result, it is possible that in other countries further or additional requirements may be imposed on a building, component, building material, production controls, etc. One example is the necessary "glue permit", which German companies need in order to carry out gluing work for the production or repair of load-bearing timber components, as this certifies that they have the necessary expertise and equipment. The different regulations are difficult to harmonize, as they have developed under different circumstances and boundary conditions in the individual countries. Stricter fire protection measures, which severely restrict timber construction, are usually based on formative events such as large city fires, from which consequences were drawn against the use of combustible building materials and large timber constructions were banned (Östman et al. 2017).

The different requirements can lead to disadvantages for planning processes abroad, as increased effort is required to meet the corresponding standards. This can lead to additional uncertainties during the planning process if the existing regulations are not understood. This also makes standardization more difficult (Branco Pedro et al. 2010).

The additional requirements and restrictions imposed on timber construction and the various components can lead to increased costs, which limit competitiveness and reduce the advantage of faster construction due to the high degree of prefabrication.

Furthermore, for half of the European countries there are no specific building regulations for existing buildings (Branco Pedro et al. 2010). This is problematic, as timber construction has great potential, especially within cities, in the course of redensification in the course of extensions and renovations. For this reason, uniform regulations are required on how to deal with an intervention in existing buildings and which additional services must be provided.

It would again be expedient to harmonize the building regulations with the same requirements for the components and the execution. As already described, this is hardly conceivable due to the individual national interests and the historical development of the building regulations. Furthermore, an agreement on certain limit values and

The introduction of safety regulations is a lengthy process which, even if implemented only after a certain period of time, therefore facilitates the market penetration of timber construction. For this reason, other problems and their proposed solutions are probably simpler and faster methods to reduce barriers in multi-storey timber construction.

3.4.3.3 Access

As described above, the harmonization work mainly concerns standards for testing and design methods according to which any harmonized construction product can be tested and bear the CE marking. This process defines how a product behaves in a fire test, but not when it can be used. In one country a product with a specific CE marking can be used for all types of workplaces, while in another country it can only be used in office buildings or not at all. This difference between standards and building regulations is not regulated by the Commission, but it can be a potential barrier to trade. The differences may also affect the general level of fire safety in a building. As the CPR focuses on product standards and not on building regulations, each contractor must identify the requirements that apply to his product and the criteria that need to be checked in order to be accepted by the authorities in each country.

The building regulations determine which products may be used. However, these regulations are different and companies must comply with different rules. For a company that wants to develop and market products, it is important to understand the regulations. A company that wants to enter the European market must have access to and understand the building regulations of each country.

(Ericsäter und Bergström 2015) are concerned with how demanding it is to design a fire safety concept due to the different building regulations. Their study examines how easily a company can access the building codes of 10 European countries (The Czech Republic, Denmark, France, Germany, Italy, Netherlands, Poland, Spain, Sweden and UK) and how easy it is to understand and implement them. Here a large variation in accessibility was noted, but generally described as poor, as in some countries no websites or even building codes could be found.

Also within the personal research during the project work it is noted that some countries do not provide their building regulations or they are very difficult to find. The publication of these is also rarely carried out by the same ministries, which is why a standardised query is not possible.

Furthermore, it is registered that not all European countries offer their building regulations in English. This makes it impossible for foreign planners to comply with the legal framework conditions, since even with an unofficial translation, errors and uncertainties regarding wording and regulations can occur. This can be a barrier to trade for all persons who are not familiar with the languages of the individual countries but who pursue trade objectives outside their own country.

Access to these documents should be facilitated. To this end, the individual countries must make their building regulations public, easily accessible and also provide English translations that have been declared officially recognised. At the same time, the websites must also have the option of being accessible in English. Another useful measure would be to explain the hierarchy and structure on the relevant website and to guide the visitor to the right documents and contacts.

If, as in Germany or Austria for example, regional regulations apply, it is useful to display these collectively on a platform in order to simplify a search for the legal requirements applicable in a specific case.

3.4.4 Climate and energy policies

As a renewable raw material and CO_2 storage, wood offers considerable advantages over conventional building materials. However, it is problematic that this is only incompletely reflected in the market prices, since, for example, CO_2 emissions that occur during the production of building materials are covered by the EU Emissions Trading Scheme, but the low certificate prices set have only little effect on the manufacturing costs. In addition, there is "carbon leakage" at industrial plants, where it can be assumed that a shift in CO_2 emissions will take place. These receive a higher share of free certificates (EU ETS). This is the case, for example, with cement manufacturers.

Policies should provide incentives to take account of environmental costs in building materials, thereby reducing distortions of competition. Against this background, emissions trading is an appropriate instrument. To this end, policy-makers must raise the price of emission certificates compared to today's levels in order to correctly reflect the environmental costs incurred in the production of, for example, steel, cement and aluminium, and thus promote the positive environmental balance of wood.

In the CPR, point 7 of Annex I sets out the sustainable use of natural resources as a basic natural requirement. This includes in particular the reusability or recyclability and durability of construction products. Furthermore, the environmental compatibility of raw materials and secondary building materials plays a role. However, these requirements are not concretized by legal regulations or by the building codes within the member states of the EU. As a result, the advantage of wood over mineral building materials is not explicitly exploited, which can result in obstacles in use and distribution. For this reason, it is recommended to set sustainability requirements for building products based on the CPR (Ludwig et al. 2017).

It is also possible to take environmental criteria into account when awarding public contracts. It is important that the awarding authority concerned has an interest in this or is obliged by appropriate legislation to give preference to wood products. A further effect of using wood in public building projects is the general spread of timber construction and the resulting impact on the population. For this purpose, influential timber construction associations are necessary to present corresponding interests to the responsible persons.

A further instrument to evaluate buildings with regard to their sustainability are life cycle analyses (LCA) and calculations regarding life cycle costs (LCC). This makes it possible to compare the extent to which CO_2 emissions, for example, are generated during the construction of a specific building, depending on the construction method.

The problem with these is the existing system boundaries, which do not fully capture the full direct and indirect effects of a construction product or building. In addition, there are no standard solutions, as each building is unique and many aspects are context-specific. Furthermore, the life cycle of the materials used during the life cycle of a building varies, making it difficult to estimate the impact on the overall balance. The available data from databases is often based on production methods of companies whose region or technological use deviates from the actual environmental conditions, which leads to errors in the calculation (Giesekam et al. 2014).

Since LCAs are models, simplifications are always associated with them. Also, the many variables that influence a production cycle (transport route, transport type, etc.) as well as the different boundary conditions of the individual countries cannot be fully mapped. Further research work is necessary for many products in order to be able to map all life cycle phases as accurately as possible and for different regions, thus enabling more meaningful and precise analyses. However, this method represents an overall instrument for promoting sustainable construction methods such as timber construction.

One measure to use this planning tool in the sense of timber construction could be the mandatory implementation of an LCA in the early planning phase. This would show the client alternative construction possibilities and methods of construction and provide him with a corresponding decision-making aid. At the same time the degree of awareness of the possibility of multi-storey timber construction can be increased. The disadvantage is, however, that this requires an increased expenditure of time and effort with the associated costs in order to create and calculate the different variants.

In addition, government support programmes can promote innovation in the industry. Suitable measures include subsidies for sustainably constructed buildings based on certification. Within the framework of these schemes, the greenhouse gas emissions associated with the manufacture and disposal of construction products should also be included in the assessment. The mandatory introduction of building certifications for public buildings can lead to increased public awareness. Moreover, the systems set the course for the future quality of the building already in the early planning phase. For example, the building owner determines in advance what standard he wants to achieve with regard to the respective certification system.

Another instrument could be the introduction of a mandatory timber construction quota in the individual countries. This requires further research in the areas of sustainability, end-of-life scenarios and health in order to have a broad basis of arguments for the use of wood. However, a European regulation is unlikely and not target-oriented, as different boundary conditions (especially in availability and building culture) exist, which make the acceptance of such measures difficult.

4 Opportunities

The total costs of buildings differ between countries for timber and conventional constructions. In general, it can be said that due to the higher price of materials and the additional costs of fire protection, timber construction can incur additional costs of up to ten percent, which cannot be fully offset by the cost savings that can be achieved through timber construction (Mahapatra et al. 2012). However, in countries with longer experience, such as Sweden, cost competiveness is already achieved (Hurmekoski et al. 2015) (Shmuelly-Kagami 2008). The savings potential lies in the lower costs for foundation work, as wood, due to its lightness, has to transfer less load to the subsoil. For the same reason, lower transport charges are possible. Further cost savings can be achieved through improved quality control, industrial prefabrication of components (faster construction of the building) and easier assembly work. Further potential lies in the increasing experience gained from built multi-storey timber structures. With increasing construction, production costs could be reduced due to the influence of "learning" the emerging construction system, as products and value chains can be improved (Mahapatra und Gustavsson 2009).

The construction sector is responsible for one third of all greenhouse gas emissions worldwide (Poulden Gervase 2009). In order to achieve the defined climate targets, there is therefore great potential for savings. The emissions are divided between the energy required in operation and the energy incorporated in building materials during production and disposal (grey energy). Due to the long service life of buildings (usually measured at fifty years), the decisions made are valid for a long period of time. For this reason it is necessary to pay attention to the influence of the choice of materials already now when constructing new buildings. Wood as a renewable raw material and long-term CO_2 storage offers the optimal conditions for this. By harvesting mature trees and subsequently replacing them with seedlings, CO_2 is "stored" in the building, while more CO_2 is bound by the seedlings. The use of wood as a supporting structure instead of the classic concrete or brick construction methods can save 1.10 tons of CO2 per m^3 structure material (Frühwald 2007). Furthermore, the by-products of the production of wood products can be recycled (see Figure 4-1). After the use phase of a building, it is possible to recycle the used wood components so that the bound CO_2 portion is not released into the atmosphere. As stated in “2.2.3 Standard solutions” there may occur some limitations. Due to the complex structures and connection details sorting can be difficult and costly during demolition work like e.g the removal of screws and nails (Teischinger 2016). Other limitations can be preservative treated and fire retardant treated wood products as these contain the potential for the contamination of wood recycling streams if not separated correctly (Morrell 2015). After a cascade of recycling, wood material can be used for bio-energy production.

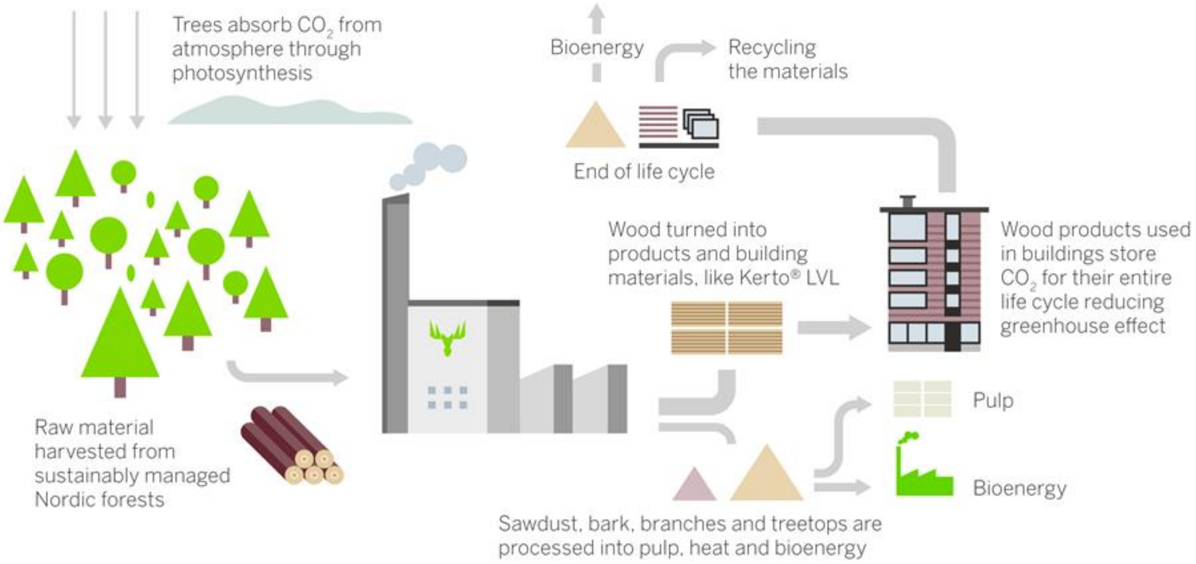

Figure 4-1: Carbon storage for life-cycle of timber buildings (https://www.metsawood.com)

There is no doubt that the use of renewable resources contributes to climate protection (Horx-Strathern et al. 2017). However, a new development is the consideration of the life cycle of a building material - consisting of production, use and disposal - which is then included in the official life cycle analysis of buildings. This enables a direct and clear statement to be made about the ecological quality of a building. Based on this, the aim is to promote awareness of the use of ecological materials and to support their use. Wood can make a major contribution not only in terms of the CO_2 balance, but also in terms of the amount of energy used to manufacture and dispose of the wood products (grey energy), which is lower than in traditional construction methods (Shmuelly-Kagami 2008).

One of the greatest potentials of the future for timber construction lies in the increasing urbanisation and the associated lack of space and living space in the conurbations. For this reason, redensifications and extensions are necessary to develop new living space and increase the occupation density. Here, wood offers the advantage of a comparatively low weight, so that extensions to existing structures are possible. Due to the high degree of prefabrication, short construction times and thus less disturbance for residents can be realized. In addition, no major interventions in the environment are necessary as with traditional construction methods, so that dust and noise pollution are reduced. Also the more precise manufacturing simplifies the connection of the components to the existing substance. Furthermore, wood can be used to modernize existing buildings (for example, by means of curtain walls) in order to reduce energy consumption.

There are a number of positive wood attributes that currently have little or no market value in stakeholder decisions. Wood as a surface cladding in interiors can reduce the stress level of the occupants, balance the interior humidity due to its hygrothermal behaviour, prevent bacterial growth and create a warm atmosphere. Therefore, if there were no obstacles to leaving wooden interior surfaces visible, the general perception of the use of wood in construction could be sustainably improved by the positive physiological and psychological effects of wooden interiors on people (Hurmekoski et al. 2015).

5 Summary

A complete list of parameters that have a negative impact on a widespread application for timber construction is potentially infinite and depends on the people, regions and views involved. However, the barriers described in the report are intended to provide an overview of the basic barriers that exist. These are also summarised in a table in Annex A.1. Another table describes additional barriers that have emerged during the analysis of the scientific papers and articles, but which are not explicitly addressed in the report.

Many of the obstacles mentioned can be attributed to a lack of knowledge about wood as a building material. As a result, there are negative prejudices in the population about the fire behaviour and durability, which can reduce interest in the construction method and, accordingly, demand. Even if important decision-makers such as builders, architects and engineers only have a lack of specialist knowledge in this field due to a lack of training opportunities or experience because of the non-existent timber construction tradition or lack of resources, it is likely that in cases of doubt, people will speak out against timber construction. Therefore, information campaigns and better further training opportunities must be created to increase interest and expertise. Timber construction and fire safety engineering should be integrated in civil engineering studies of public education institutions. A European education program could be developed within this area

The development and provision of standard solutions as well as component catalogues and experience reports of already completed projects increase the range of advice and information available to interested planners. In the course of increasing experience, leaner processes can be achieved, which reduce costs, thereby increasing competitiveness compared to classical construction methods and, conversely, reducing financial risk.

Due to the small and medium-sized structure of the timber construction industry, it is questionable to what extent an increased demand can be met by it. The climate change with its harmful consequences for the forestry industry can also lead to uncertainties with regard to the future security of supply. For this reason, it is conceivable to form joint ventures in order to expand capacity limits. In addition, political subsidies can facilitate the expansion of capacities. Furthermore, sustainable forestry must be ensured in order to guarantee security of supply in the future.

A further problem is posed by the different building regulations in the individual countries, which restrict timber construction to varying degrees due to historical development. A table with the current requirements and possibilities for the use of timber construction components can be found in Appendix A.2. This makes planning more difficult for companies operating nationwide and does not necessarily reflect the possible state of the art. Also the different construction and the partly difficult access to necessary documents make the understanding of the building regulations more complex. For this reason, a harmonization of the building regulations would be desirable, but is hardly feasible due to the EU's subsidiarity principle. Nevertheless, it would be helpful to adapt the building regulations to a performance-based approach and to structure the documents in a uniform way. A standard and state-approved translation into English is also desirable.

Due to the relatively new construction products and systems in timber construction, there are no harmonized standards for many construction products. Also, new developments cannot be immediately translated into standards due to the lengthy process. At the same time there are knowledge gaps which are reflected in missing or incomprehensible limit values. The consequences are uncertainties and nationally differing verification methods. For this reason, further research is necessary to close these gaps and to increase the understanding of the behaviour of building products and building materials. In addition, the potential risk can be minimized.

Within this research project it is possible to collect missing information about the adhesive behaviour at high temperatures and thus contribute to close knowledge gaps. The influence of different types of adhesives in different engineered wood systems will be clarified on the basis of tests with fire and temperature loads. On the basis of these tests it is possible to better foresee the behaviour of the structure on exposure to temperature and thus to create planning and dimensioning possibilities that increase the safety level.

A further obstacle can be the non-consideration of climate protection contribution of the construction method, whereby the great advantage of wood as a renewable raw material and CO_2 storage has only a minor influence on the decision makers. In this context, greater attention to environmental aspects in public projects is conceivable, which can also have a signal effect on the general public. A higher CO_2 price in the EU Emissions trading system is also an effective instrument for promoting sustainable construction methods. This requires the interest of politicians, who can take appropriate measures to promote timber construction.

In the evaluated surveys, only new buildings are usually considered. For this reason, it is possible that there are other barriers to timber construction in terms of renovation for buildings that are not considered and mentioned in this report.

There are also regional differences between the individual EU countries in terms of their initial position and the boundary conditions for timber construction. For this reason, the potential for timber construction varies, as the barriers and restrictions may be different across countries and the proposed recommendations for action have an unequal impact. In addition, there may be other barriers that are not listed in the report and only apply to specific countries. To overcome knowledge gaps there should be the possibility for inexperienced countries in timber construction to learn from experienced ones.

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Appendix A

A.1

Social			Technical		
Barrier		**Recommendation**	**Barrier**		**Recommendation**
Public perception	• Safety concerns • Lack of education possibilities • Awareness of properties of wood • Lack of information and advice • Perception of the contribution to climate protection	• Information campaigns • Certification systems	**Lack of expertise and experience**	• Lack of experienced designers and planers • Tradition and culture • Lack of knowledge of building codes • Knowledge exchange between industry and research facilities • Lack of education possibilities	• Knowledge transfer between research institutions and industry • Early cooperation of the involved • University education • Catalogues of components • Experience reports • Further training opportunities
Knowledge of stakeholders	• Lack of education possibilities • Tradition and culture • Lack of experienced designers and planers • Lack of information and advice • Consumer preferences	• University education • Catalogues of components • Information platform • Research Funding	**Wood Industry**	• Rate of adopting prefabrication and industrialization • Lack of capacity • Location and market access	• Capacity increase • Working groups • Political promotion
			Standardisation	• Missing standard solutions • Lack of Knowledge on details • Lack of End-of Life planning	• Catalogues of components • Database • Guides for timber construction
			Concerns about fire safety	• Fire Safety restrictions • Lack of knowledge in fire safety possibilities	• Harmonisation of building codes • Exchange of knowledge and experience • Communication between research and the public • Risk assessment
Economic			**Political**		
Barrier		**Recommendation**	**Barrier**		**Recommendation**
Availability	• Wood supply • Market potential • Lack of capacity • Climate change	• Sustainable forestry • self-contained value chain • Cascade use • Interest groups • Early cooperation of the involved • Standard solutions	**Standards**	• Missing Standards • Actuality of standards • Long process	• Research Funding • Participation of industry in standards work • Ongoing adaptation
Planning	• Lack of skilled workers • Lack of experience • Missing standard solutions	• BIM • Experience reports • Catalogues of components	**ETA**	• Complexity of verification process • National requirements	• Harmonisation of standards • Leaner process for ETA • Harmonisation of building codes • Requirement documents for building products
Insurance	• Higher policy • Financial uncertainty	• Database • Information campaigns	**Building regulation**	• Formulation and structure • Comprehensibility	• Perfomance based • Structural adjustment • Guidelines
			Additional Requirements	• Design limitations • Increased expenditure	• Harmonsiation of building codes • Easy access to building codes • Explanation of use
			Access	• Accessability • Language problem	• Locatability • Easy access • English translation
			Climate and energy policies	• too low CO2 pricing	• efficient emissions trading • Consideration of LCA and certification systems • Political promotion

Social	Technical	Economic	Political
• Willingness of construction networks • Health aspects • Consideration of environmental impacts • Lack of information and advice • Branding and marketing unimportant • Lacking project communications	• Integration of the technical building equipment • Material limitations • Research Coordination • Showcase examples	• Financial uncertainty • Competition with the energy sector • Cost competiveness	• Limited support from municipalities • No national timber strategies • Consideration of climate protection contribution

Based on:

(Forestry Statistics 2007) (Alderman 2013) (Arora et al. 2014) (Baudin 2003) (Bengtsson 2009) (Branco Pedro et al. 2010) (Bysheim und Nyrud 2008) (Castaldo et al. 2009) (Dederich 2013) (Denizou et al. 2007) (DTI 2009) (Ebert et al. 2017) (Ericsäter und Bergström 2015) (European Commission 2014a) (Foliente 2000) (Franzini et al. 2018) (Gallagher 2018) (Gerard et al. 2013) (Giesekam et al. 2014) (Gosselin et al. 2017) (Hansen et al. 2014) (Horx-Strathern et al. 2017) (Hurmekoski et al. 2014) (Hurmekoski et al. 2015) (Hynynen 2016) (Januzi-Cana 2017) (Jonsson 2009) (Kremer und Symmons 2016) (Leonard et al. 2009) (Ludwig et al. 2017) (Mahapatra und Gustavsson 2009) (Mahapatra et al. 2012) (Nwaogu et al. 2015) (O`Connor 2006) (Östman 2002) (Östman et al. 2017) (Östman und Källsner 2011) (Rametsteiner und Oberwimmer 2007) (Ruuska und Häkkinen 2016) (Sardén Ylva 2005) (Sathre und Gustavsson 2009) (Shmuelly-Kagami 2008) (Sikora 2018) (Sousa et al. 2019) (Teischinger 2016) (Visscher et al. 2003) (Winter 2016) (Wolski et al. 2000)

A.2

Table: Euroclass D products allowed in multi-storey timber buildings

Country	Allowed Number of storeys (or height of building in meters) for D class products							D/Dfl class products allowed in buildings with max number of storeys under prescribed rules (see first column)																	Reference	Comments
	Load-bearing structures					External cladding		Internal walls/ceilings												Floorings		Firewall	Stairs	Elevator Shaft		
								Load bearing members of elements in						Surface of seperating elements in												
	Prescribed rules (preaccepted solutions)		Performance based (PB)		Protection required			Corridor escape routes		Stairwell escape routes		Within apartment		Corridor escape routes		Stairwell escape routes		Within apartment								
						Sprinklers		Sprinklers		Sprinklers		Sprinklers		Sprinklers		Sprinklers		Sprinklers		Escape routes	Within apartements					
	Storey	Height [m]	Storey	Height [m]		no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes							
Austria	6		No limit		No	6	6							-	-			+	+	-	+				Österreichisches Institut für Bautechnik	
Belgium	See PB		No limit		No	3 (10m)	3 (10m)							-	+ [a]			+	+	-	+				Cost Action 1404	
Czech Republic	3-4	12				3-4 (12m)	3-4(12m)							-	-			+	+	-	+				Cost Action 1404	
Denmark	3-4	9,6 m to top floor level	No limit	<22 m		(3-4) 20%, but not with vertical fire spread risk	(3-4) 20%, but not with vertical fire spread risk			-	+ only in old buildings			-	-	-	+ only in old buildings	20%	20%	-	+	-	-	-	Bygningsreglementet	
Estonia	4 / 8 [b]		No limit		No	8	8	+	+	+	+	+	+	-	-	-	-	+	+	+	+	-	+	+	Decree No.17 of Ministry of Internal Affairs	
Finland	2 / 8 [b]	9 / 28 [b]	No limit	No Limit	$K_2$10/$K_2$30	2-4	8	+	+	+	+	+	+	-	-	-	-	+	+	+	+	-	+	+	Ministry of the Environment Finland	
France	No limit		No limit		No	28m [c]		+	+	+*	+	+	+	-	-	-	-	+	+	+	+	-	-*	-	Parlement en matière de logement et de rénovation énergétique des bâtiments	*For residential building stairs'structure has to be non-combustible but structure of stairwell (load bearing part can be in wood). In Public bulding, stairwell load bearing structure can't be combustible (nor stairs'structure itself)
Germany	4-5	13	No limit	-	$K_2$60	3 (7m)	3 (7m)	+	+	+	+	+	+	-	-	-	-	+	+	-	+	+	-	+	IS-Argebau	
Greece	No limit		No limit		No	No limit	No limt							-	-			+	+	+	+				Cost Action 1404	
Ireland	3	10	No limit			≥5	≥5							-	-			+	+	+	+				Cost Action 1404	
Italy	See PB		No limit		No	- (12m)	- (12m)							-	-			-	-	+	+				Cost Action 1404	
Latvia	3/4/(6a)	8/14/(18a)	Not used		No/B-s1,d0/(K260a)	6	6	+/-/(-)	+/-/(+)	+/-/(-)	+/-/(+)	+/-/(-)	+/-/(+)	*	*	*	*	*	*	+	+	*	*	*	Ministru kabineta noteikumi	*In Latvian fire safety regulations Reaction to fire class is applied to structural parts of a building. There are no general rules for surfaces. There are some requirements for special situations
Netherlands		13	No limit			3-4	>=5							-	-			+	+	+	+				Cost Action 1404	
North Macedonia	2					2																			Cost Action 1404	
Norway	4		No limit		$K_2$10 D-s2,d0 / B-s1,d0 / A2-s1,d0	2-3	*	+	+	+	+	+	+	-	-	-	-	+**	+**	+	+	-	+	+**	Direktoratet for Byggkvalitet	Norway has performance-based regulations, with a guidance document describing minimum performance/properties to fulfil the regulations. However, other solutions can be used in a holistic performance-based approach. Sprinklers do not automatically give any reductions/allowances. * D-class external cladding can in some cases be used in buildings up to 4 storeys, and if measures to prevent fire spread on facade are taken then D-class cladding can be used unlimited. ** D-class surfaces not allowed in fire comp. > 200 m² in buildings with 3-4 storeys, and not in shafts/cavities.
Poland	3-4	12			B-s1,d0	- (25m)	- (25m)							-	-			+	+	-	+				Cost Action 1404	
Portugal		9 (single family)				- (28m)	- (28m)							-				+		-	+				Cost Action 1404	
Slovakia	2-4		Not permitted		EI	- (12m)	- (12m)							-	-			+	+	+	+				Cost Action 1404	
Slovenia	3 / 5 [b]		No limit		EI30/EI60	3 (10m)	3 (10m)							-	-			-	+	+	+				Cost Action 1404	
Spain	See PB		No limit			- (18m)	- (18m)							-	-			+	+	-	+				Ministerio de Transportes, Movilidad y Agenda Urabana	
Sweden	See PB		No limit		No	2	>=5							-	-			-	+	+	+				Cost Action 1404	
Switzerland		30	No limit		>30m K30-RF1	- (30m)	- (30m)							-	+			+	+	+	+				Interkantonales Organ Technische Handelshemmnisse	
Turkey	3		No limit		F30B2/F60AB	3	3							-	-			-	-						Cost Action 1404	
United Kingdom	See PB		No limit			- (18m)	- (18m)							-	-			-	+	-	+				Ministry of Housing, Communities & Local Government	
a	Fire detection is the required active means					+	can be used																			
b	With sprinklers					-	can not be used																			
c	Applicable for dwellings; more than 4 storeys requires compliance with French facade test																									

Table: Fire resistance of building components

Countries	National Prescriptive Fire safety level	Fire resistance requirements [min] depending on number of storeys																				Comments
		1 - 2				3 - 4				5 - 6				7 - 8				higher than 8 storeys				
		sprinklers		no sprinklers		sprinklers		no sprinklers		sprinklers		no sprinklers		sprinklers		no sprinklers		sprinklers		no sprinklers		
		R	EI	R	EI	R	EI	R	EI	R	EI	R	EI	R	EI	R	EI	R	EI	R	EI	
Austria				30	30			60	60			90	90			90	90			90[a]	90[a]	[a]<22m ≤7m R(EI) 30; ≤11m R(EI) 60; <22m R(EI)90
Belgium				60	60			60	60			60	60			60	60					
Czech Republic				45[a]				60[a]				-	-			-	-					[a]Underground floor excl, 30 for highest storey
Denmark		60	60	60	60	60	60	60[a]	60[a]	120[b]	60	120[b]	60	120[b]	60	120[b]	60					[a]Protection to prevent charring required, $K_2$60 A2-s1,d0 [b]The fire safety must be equal or better than a building made of non combustible materials. The height to top floor level decides the fire resistance 12m< height < 22 m
Estonia				60/30[a]	60/30[a]			60	60	60[a]	60[a]	60	60	60[a]	60[a]	60	60	120[b]	120[b]	120[b]	120[b]	[a]residential houses and offices of timber have to be sprinklered; [b]timber elements have to be encapsulated ; requirements can be higher for higher fire load
Finland		30/0[a]	30	30/0[a]	30	60	60	-	-	60	60	-	-	60	60	-	-	-	-	-	-	[a]Depending on fire class of the building
France	Housing			15/30[a]	15/30[a]			30/60[b]	30/60[b]	No benefit on REI	No benefit on REI	60	60	No benefit on REI	No benefit on REI	60[c]	60[c]	No benefit on REI	No benefit on REI	90/120/∞[c]	90/120/∞[c]	aVertically/horizontally / b: limit is at 8m, not number of storeys (what is important is the height of the accessible floor with a door => duplex/triplex with an entrance at <8m is allowed and fire requirement is then 30min. If not => requirement is 60min)/ c: real limit is not 8 storey but 28m for the height of the last accessible floor. Between 28-50m, requirement is 90min and after 50m requirement is 120min or must be "∞" if fire engineering is used
	Others			0/30[a]	0/30[a]			0/30/60[a]	30/60[a]	No benefit on REI	No benefit on REI	60/90	60/90	No benefit on REI	No benefit on REI	60/120/∞[b]	60/120	No benefit on REI	No benefit on REI	120/∞[b]	120	[a]Limit is in general 8m for the height of accessible floor, but number of people in the building is also a parameter to establish fire requirement => in general it can be summarized 0min then 60 or 90min depending of the size of the building and type (public, office)/c: real limit is not 8 storey but 28m for the height of the last accessible floor, after 28m requirement is 120min or must be "∞" if fire engineering is used
Germany		30[a]	30[a]	30[a]	30[a]	60[bc]	60[bc]	60[bc]	60[bc]	60[bc]	60[bc]	60[bc]	60[bc]	-	-	-	-	-	-	-	-	[a]not in detached houses, [b]Protection to prevent charring required, [c]7m<height≤13m ≤7m R(EI) 30; ≤7m R(EI) 60; <22m bzw. 60m R(EI) 90
Greece				30				30				60				60						Underground floor excluded
Hungary				30	30			90/45[a]	-			150/45[b]										[a]Vertically/horizontally, bonly in five storeys in timber
Ireland				30	60			60[a]	60[a]			60[a]	60[a]			60[b]	60[b]					[a]5m<height<20m, [b]90 for 20m<height≤30m
Italy				30[a]				30[a]				60[a]	-			60[a]	-			90/120[a]		[a]for dwellings >32m R 90; >80m R 120
Latvia	U1a	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Timber structures are not allowed
	U1b	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Timber structures are not allowed
	U2a	N/A	N/A	N/A	N/A	60[abcde]	60[abcde]	N/A	N/A	60[abcde]	60[abcde]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	[a]Fire resistance for load bearing structures not used as fireseparating structures; [b]Height limitation for upper floor level is from 8 to 14 m (by error this rule is not applicable for buildings with smaller amount of floors); [c]Load bearing structures shall be treated with fire retardants (B-s1,d0 shall be achieved); [e]Building shall have two evacution routs [d]Applicable for office type buildings (National end use category V)
	U2b	30[ab]	30[ab]	30[ab]	30[ab]	30[ab]	30[ab]	30[ab]	30[ab]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	[a]Fire resistance for load bearing structures not used as fireseparating structures; [b]Height limitation for upper floor level is from 8;
	U3	-	-	-	-	-	-	-	-	60[ab]	60[ab]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	[a]Fire resistance for load bearing structures not used as fireseparating structures; [b]U3 fire safety level buildings can be built over 8 m up to 18 m (6 floors), if the U2a fire safety level fire resistance requirements are met
Netherlands				30[a]				60[a]				90[a]				90[a]						[a]+30min for fire load>500kJ/m^2
Norway		30[a]	30[a]	30[a]	30[a]	60	60	60	60	90/60[b] A2-s1,d0	60 A2-s1,d0	90/60[b] A2-s1,d0	60 A2-s1,d0	90/60[b] A2-s1,d0	60 A2-s1,d0	90/60[b] A2-s1,d0	60 A2-s1,d0	90/60[b] A2-s1,d0	60 A2-s1,d0	90/60[b] A2-s1,d0	60 A2-s1,d0	Fire resistance as given in the *prescriptive guidance document* (no limits given in the performance-based regulations). Sprinkler does not automatically give any reductions/allowances. [a] For some small single family dwellings R/EI 15 is sufficient. [b] Main load-bearing / secondary load bearing structure. A2-s1,d0 = All materials in the element/wall/ceiling must be A2-s1,d0.
Poland								-	-			-	-			-	-					
Portugal				30	-			-	-			-	-			-	-					
Romania				-				30	-			-	-			-	-					
Slovakia				45				-	-			-	-			-	-					
Spain				60[ab]	60[ab]			60[b]	60[b]			90[b]	90[b]			90[b]	90[b]			90/120[b]	90/120[b]	[a]30 for one-family home [b]residential buildings, social housing, school buildings and office, administration buildings/depending on use <15m R(EI) 60; ≤28m R(EI) 90; >28m R(EI) 120
Sweden				30	30			60	60			90[a]	90[a]			90[a]	90[a]					[a]60 for horizontal elements. Remember: The fire resistance depends on the fire load in the fire compartments. If wooden surfaces, then dobbel the time demand for resistance.
Switzerland				30[ab]	30[ab]			30[b]	30[b]			60[b]	60[b]			60[b]	60[b]			60/90[b]	60/90[b]	[a]no req for 1 storey [b]reducible by extinguishing system <11m R(EI) 30; <30m R(EI) 60; <100m R(EI) 90
United Kingdom				30[bc]	15			60[bc]	60			60[bc]	60			90[abc]	90[a]			90/120[ab]		[a]not in Scotland [b]residential buildings, social housing, school buildings and office and administration buildings [c]reducible by extinguishing system <5m R30; <18m R60; ≤30m R90; >30m R120

A.3

Figure A3-1: Forest area in EU/EEA/EFTA countries in 1990 & 2015

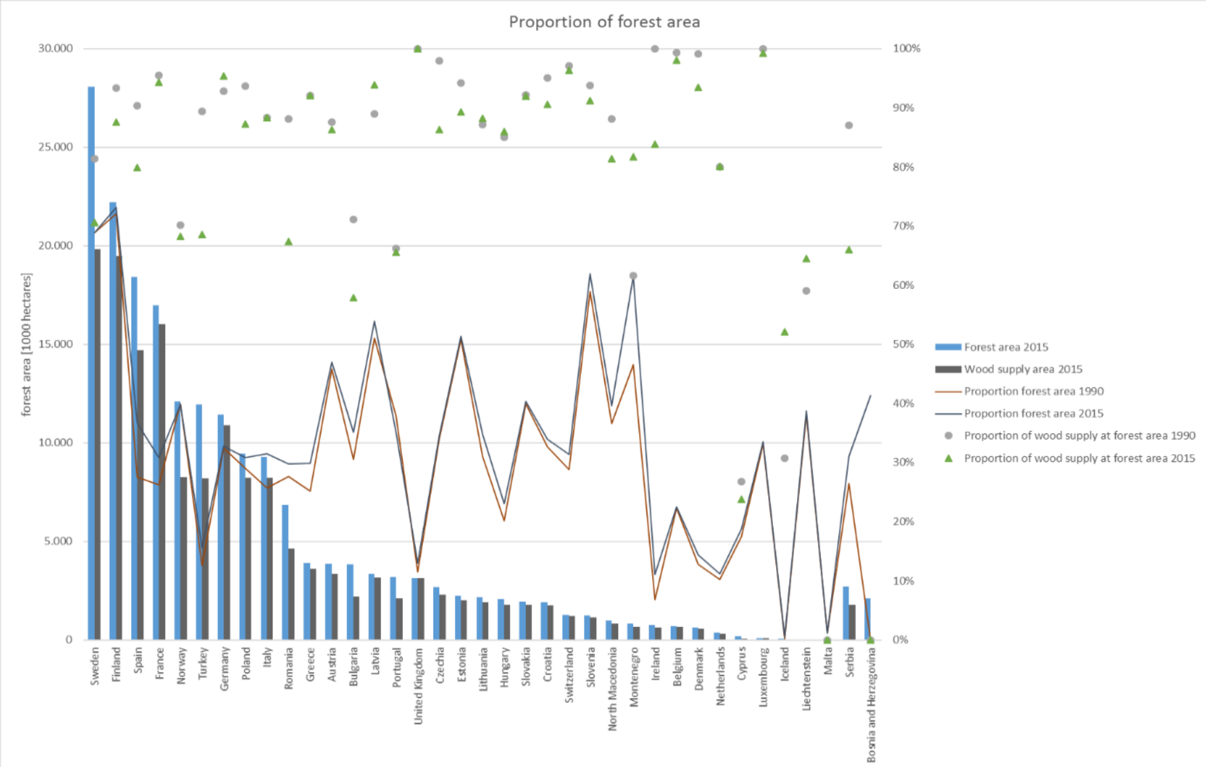


Figure A3-2: Wood supply area in EU/EEA/EFTA countries in 1990 & 2015

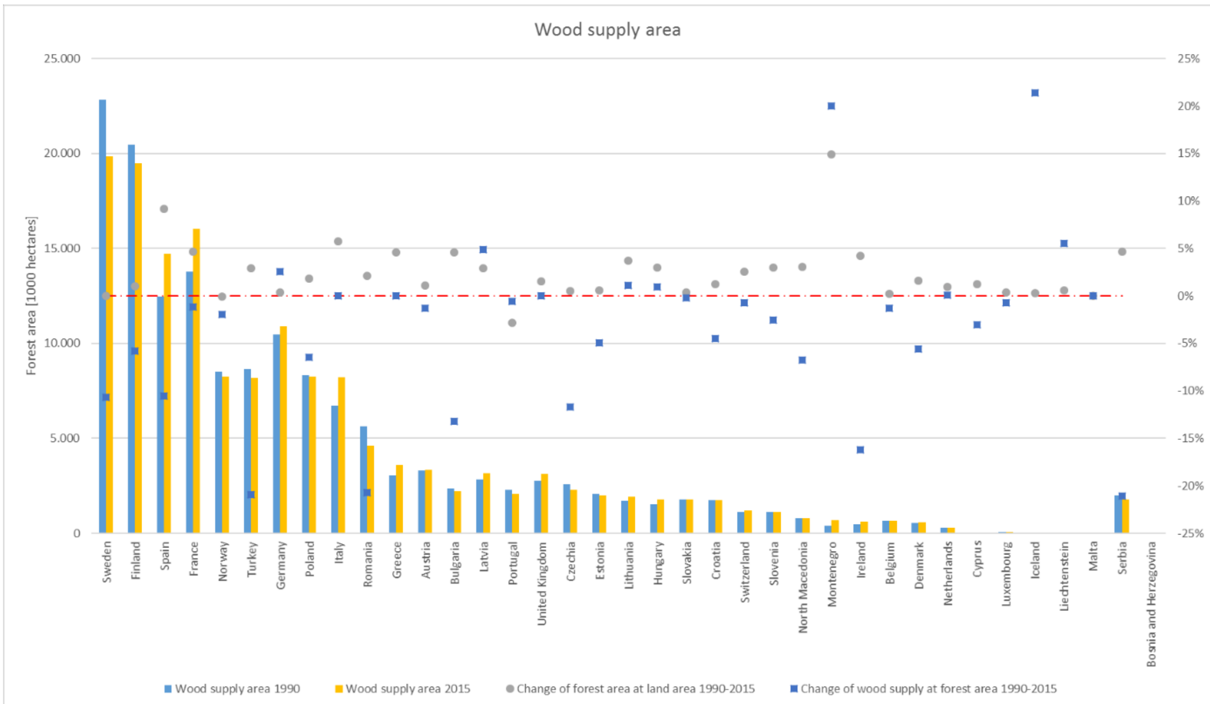


Figure A3-3: Roundwood Production in EU countries, Russia, Canada, USA, Brazil in 2000 & 2014

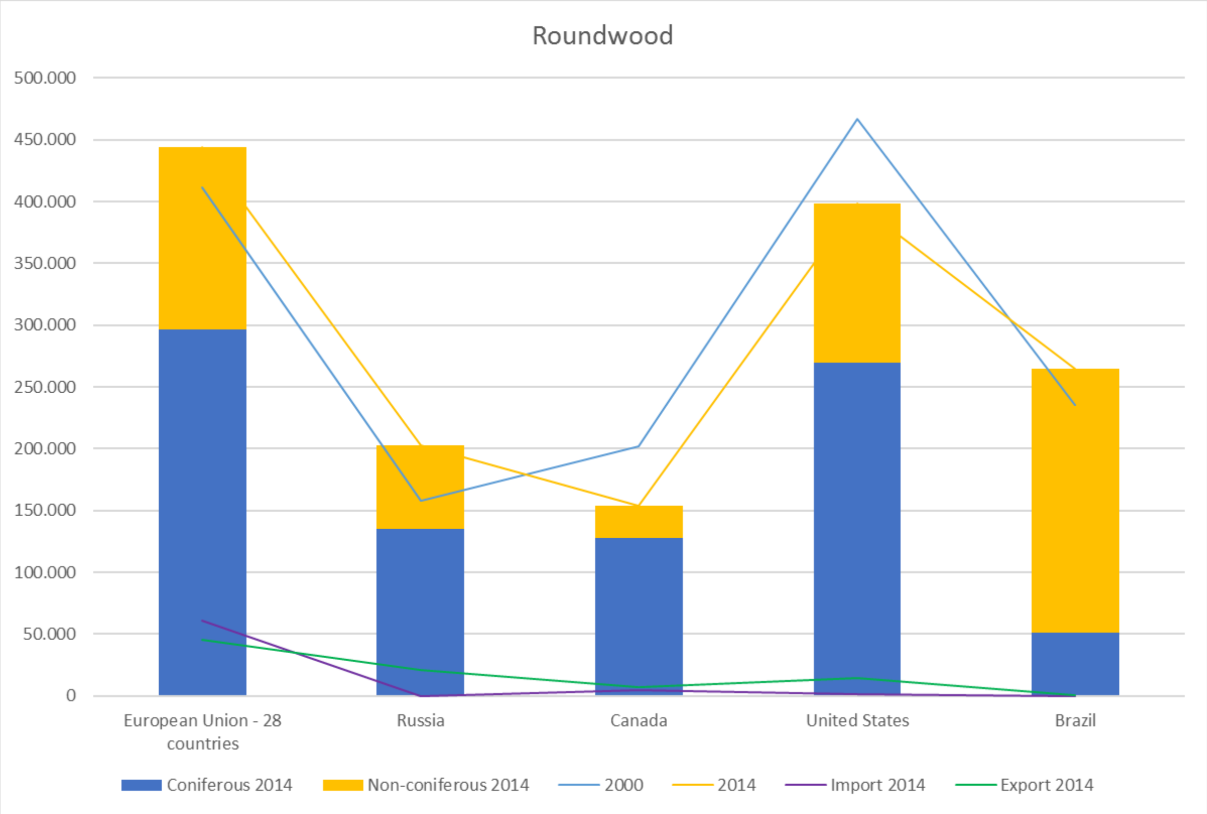


Figure A3-4: Production of engineered wood in EU/EEA/EFTA countries in 2015

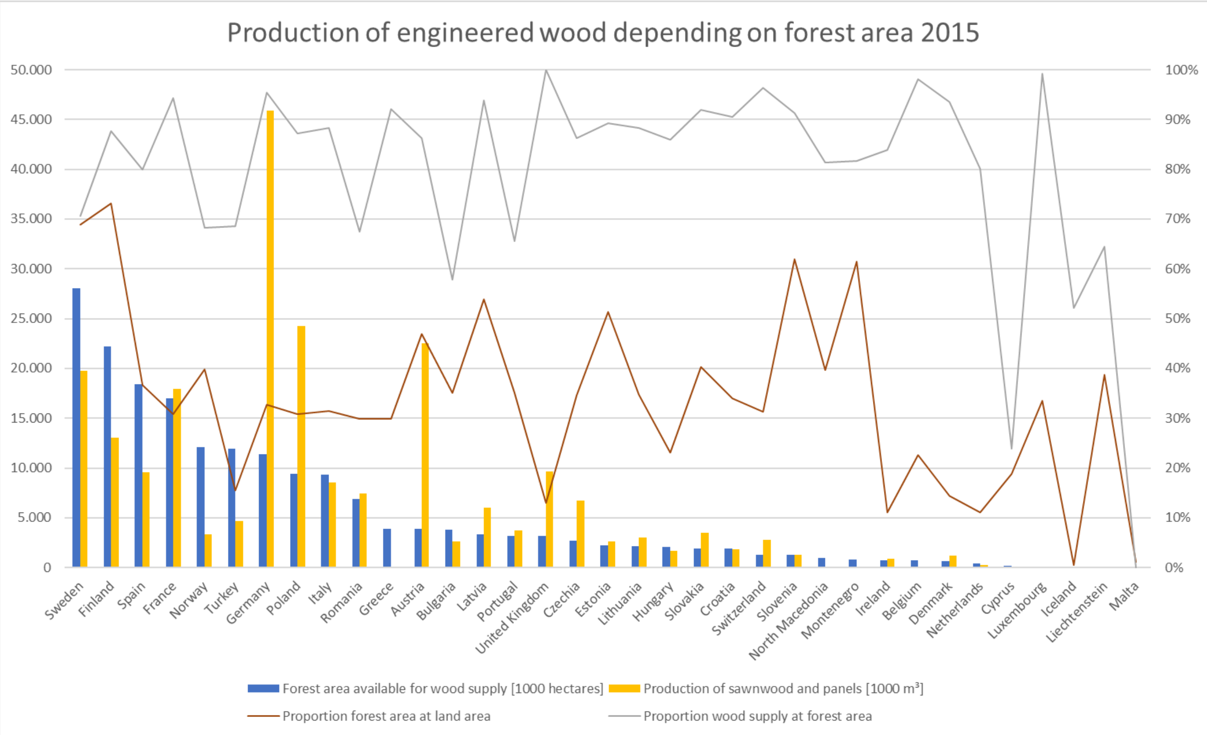
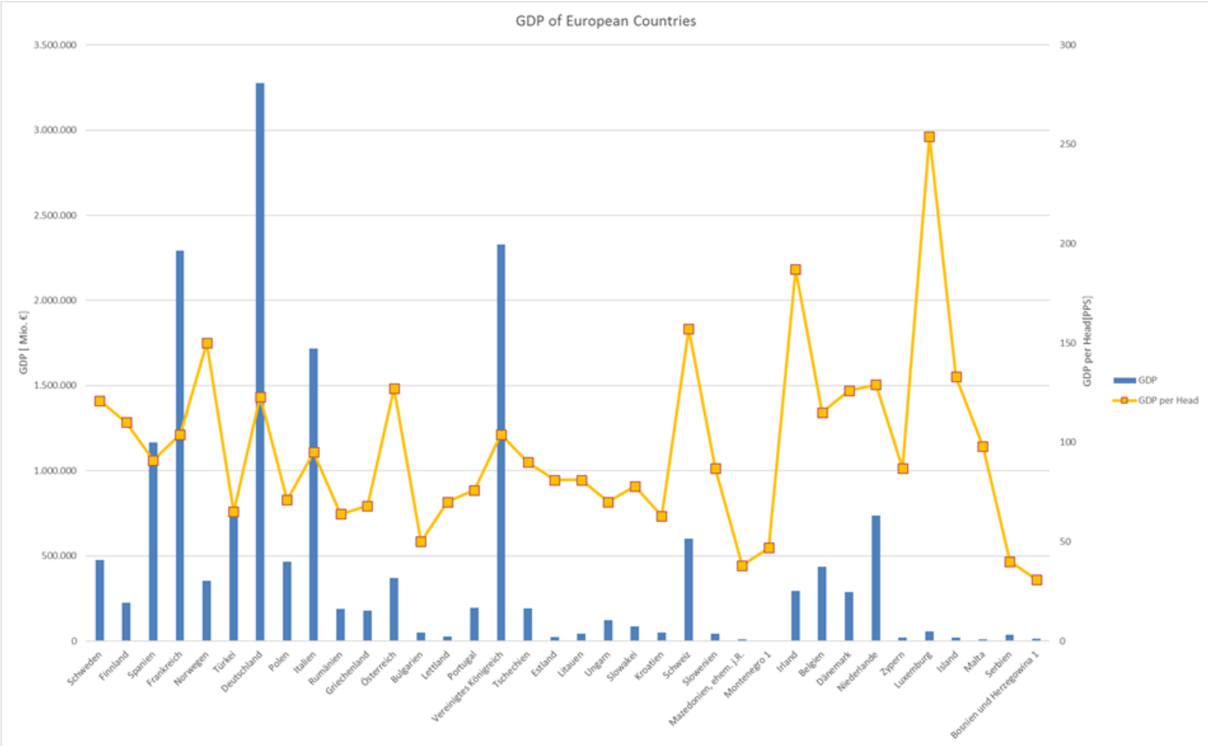


Figure A3-5: GDP in EU/EEA/EFTA countries in 2015



These tables are based on the Datasets of Eurostat.

A.4

Overview of countries covered by the literature study	
Dederich 2013	Germany, Sweden
Denizou 2007	Norway
DTI 2009	EU
Ebert 2017	Germany
Ericsäter 2015	Denmark, Czech Republic, France, Germany, Italy, Netherlands, Poland, Spain, Sweden, UK
European Commission 2014	EU
Foliente 2000	General
Franzini 2018	Finland
Gallagher 2018	UK
Gerard 2013	Global
Giesekam 2014	UK
Gosselin 2017	Canada
Hansen 2014	USA, Canada
Horx-Strathern 2017	Global
Hurmekoski 2014	Austria, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Spain, Sweden, Switzerland, UK
Hurmekoski 2015	EU
Hynynen 2016	Finland
Januzi-Cana 2017	Kosovo
Jones 2016	UK
Jonsson 2009	England, France, Germany, Ireland, Netherlands, Sweden
Kremer 2016	Australia
Leonard 2009	USA
Ludwig 2017	General
Mahapatra 2009	Sweden
Mahapatra 2012	Germany, Sweden, UK
Nwaogu 2015	EU
O`Connor 2006	Canada
Östman 2002	Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland Ireland, Italy, Netherlands, Norway, Poland, Portugal, Romania, Spain, Slovakia, Slovenia, Sweden, Switzerland, UK, Australia, New Zealand, Japan, USA, Canada
Östman 2017	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland Ireland, Italy, Latvia, Netherlands, Norway, Poland, Portugal, Romania, Spain, Slovakia, Slovenia, Sweden, Switzerland, UK

Östman 2011	EU
Rametsteiner 2007	Austria, Belgium, Bulgaria, Croatia, Denmark, Germany, Finland, France, Ireland, Italy, Netherlands, Norway, Poland, Slovakia, Slovenia, Sweden, Switzerland, Ukraine, UK, Russian Federation
Ruuska 2016	Finland
Sardén 2005	Sweden
Sathre 2009	General
Shmuelly-Kagami 2008	Austria, Finland, Sweden, Switzerland, Japan
Sikora 2018	China
Sousa 2019	EU, EFTA
Teischinger 2016	General
Visscher 2003	Belgium, Denmark, England, France, Germany, Netherlands, Norway, Sweden
Winter 2016	Global
Wolski 2000	General