

Experiences and environmental aspects of thermal modified timber in novel noise barrier elements along a motorway in Austria

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ABSTRACT

Many different types of noise barriers have been installed over the last decades using a wide variety of construction materials including wood, steel, aluminium, concrete and acryl glass. Among these materials, only wood is renewable but it has to meet the requirements of EN 460, which states that either a suitable wood species has to be selected or, when using softwoods, a suitable treatment is needed. Common practice is to use chemical treatments that contain toxic substances. Such barriers, however, are classified as hazardous waste and should be treated accordingly. Aluminium or steel barrier elements do not possess this disposal problem, since they can be recycled, but they originate from non-renewable resources. The use of *thermally modified timber (TMT)* presents an alternative to these materials as first of all it does not have a disposal problem since *TMT* can be used in hazard class 3 or even 4 (EN-355-1) without any chemical additives and secondly it is made from renewable resources. On the other hand, it is known, that thermal modification affects the mechanical properties. While stiffness remains more or less unchanged, there is a relevant decrease in strength. Another key problem is the increase in brittleness which affects the performance of joints in timber constructions in a negative way. Grading rules for structural applications do not include thermal modification as a standard procedure affecting the strength class of timber. Even the process itself is not yet standardized, though standardisation has started and pre-standards are defined by a group of experts. This means that the grading of the material and the design of the structure could not be done using standardized procedures (*e.g.* EN 1995-1-1 and EN 338). However, the CE-marking is mandatory for noise barriers according to EN 14388, and the structural requirements after EN 1794-1 have to be met. This paper describes the strategy and main outcomes when facing the above mentioned questions. The environmental impacts of the developed barrier were

studied and compared to aluminium and acrylic glass barriers. On the basis of the experiences the potential for *TMT* noise barrier systems in the future is discussed.

INTRODUCTION

Noise barriers are designed to block sound waves in the propagation path from source to receiver, and they have to fulfil two main functions, load bearing and noise reduction. In most variants load bearing is achieved by a structural frame, while noise reduction is mainly achieved by a noise absorbing material. For simple plane barriers with thicknesses less than the wavelength of sound, the height and length are the most important factors determining the degree of screening achieved. Absorptive barriers, which incorporate elements on the traffic face, absorb a significant proportion of incident sound and hence reduce reflected sound which could contribute to overall noise levels in the vicinity. A common form of construction is the use of barrier panels which are perforated on the side facing the traffic in order to allow the ingress of sound into fibrous material. An alternative is the use of panels constructed with open-textured porous materials. Absorption is achieved in these materials by frictional losses in the connected voids of the permeable layer. Natural materials of a fibrous nature will act as porous materials and thus offer an alternative to conventional porous absorbers such as mineral wool and plastic foams. Wood is a prized construction material for noise protection barrier systems. Its availability, energy balance and its impression being in harmony with natural scenery are substantial arguments for its application as noise barrier panels. Noise barriers are exposed to all possible weather conditions, leaving, especially for wooden barriers and parts, a high risk of degradation. To allow a product life of about 20 years, the wood has to be constructed and protected properly. *TMT* is a possible alternative to existing barriers, since wood is a renewable resource and the durability is derived merely from heat exposure. The expected environmental benefits are tested by a life cycle assessment (LCA) study of the *TMT* noise barrier elements, and the environmental impacts are compared to elements made of aluminium and acrylic glass.

ASSIGNING DURABILITY, STRENGTH PROPERTIES AND GRADING

The basic effects of thermal modification – compared to untreated wood – are an improved dimensional stability and an increased durability against wood destroying fungi and in some cases altered colours. Further on there are changes in density, moisture content (MC) and strength properties. The altered properties of *TMT* and their extent depend on the wood species modified and the process parameters, in particular on the *treatment temperature*. Strength properties of wood are directly affected by density and moisture content. Increasing density and decreasing moisture content both increase the strength (for tensile strength: it works for moisture contents between the fibre saturation point (FSP) to an MC of 5 – 10 %). Thermal modification leads to a decrease of density and MC. While for light thermal treatments the static strength of the modified material slightly increases, due to a lowered MC, stronger treatments with higher temperatures lead to an increasing loss of static strength, whereas any kind of thermal treatment leads to an increasing loss of dynamic strength.

Depending upon conditions to which it is subjected, wood is exposed to different risk classes (*hazard classes*) according EN 335. To cope with the challenge of the *hazard classes 3 or 4*, wood has to be carefully chosen and/or properly protected. High quality *TMT* concerning durability and strength is mainly achieved by modifying hardwoods.

Based on the final decision which species and which thermal treatment(s) will be selected for structural purposes of *TMT* the determination of durability has to be executed in order to meet the requirements of EC5. Regarding durability the EC5 states that timber and wood-based materials shall either have adequate natural durability in accordance with EN 350-2 for the particular *hazard class* (defined in EN 335-1 and EN 335-2 for solid wood), or be given a preservative treatment selected in accordance with EN 351-1 and EN 460. As *TMT* is not listed in EN 350-2 its durability class has to be determined by tests.

For constructions made out of hardwoods, less structural parameters are available than for softwoods. For *TMT* no data can be found in the relevant standards. Therefore it is required to determine these data by appropriate tests. For standard coniferous structural timber it suffices to determine only three parameters by tests, the bending strength, the modulus of elasticity (MOE) as well as the density. Other properties can be calculated based on these three parameters. This approach cannot be used for *TMT*. Therefore tests with small samples to determine the strength properties and the relevant conversion factors for *TMT* had to be carried out. All this tests were performed with *TMT "Buche forte"*. In addition untreated beech and spruce were tested as reference. The parameters tested include bending strength, MOE, tension strength, compression strength and MOE perpendicular to grain as well as density. The test results were used to calculate the dimensions and properties of the structural parts of the new developed noise barrier system. In general, the strength values of *TMT* "Buche forte" are lower than those of untreated beech and they are at the level of structural coniferous timber.

DEVELOPED NOISE BARRIER PROTECTION SYSTEM

The noise barrier elements consist of a structural frame, made out of *TMT* (spruce, beech, ash). The prototypes are made out of *thermally modified spruce* (Figure 1).



Figure 1: Noise barrier protection element road side view

The frame is mounted between two steel pillars, which are 4 or 5 meters apart. The dimensions of the frame parts were calculated for a 4 m long element. The frame consists of two horizontal and three vertical members, which are connected by stainless steel screws. The filling of the element consist of three layers. Two layers of reed and a middle layer of clay (Figure 2). The reed layers work as sound absorbers while the clay prevents the transmission of sound through the element. Except for the steel connectors the whole element consists only of natural and sustainable materials. The sound absorbing performance of the standard element can be improved through enlarging the

surface of the absorber. One kilometre of the developed noise barrier system is actually installed over a length of one kilometre at the A-22 motorway close to Vienna, Austria.

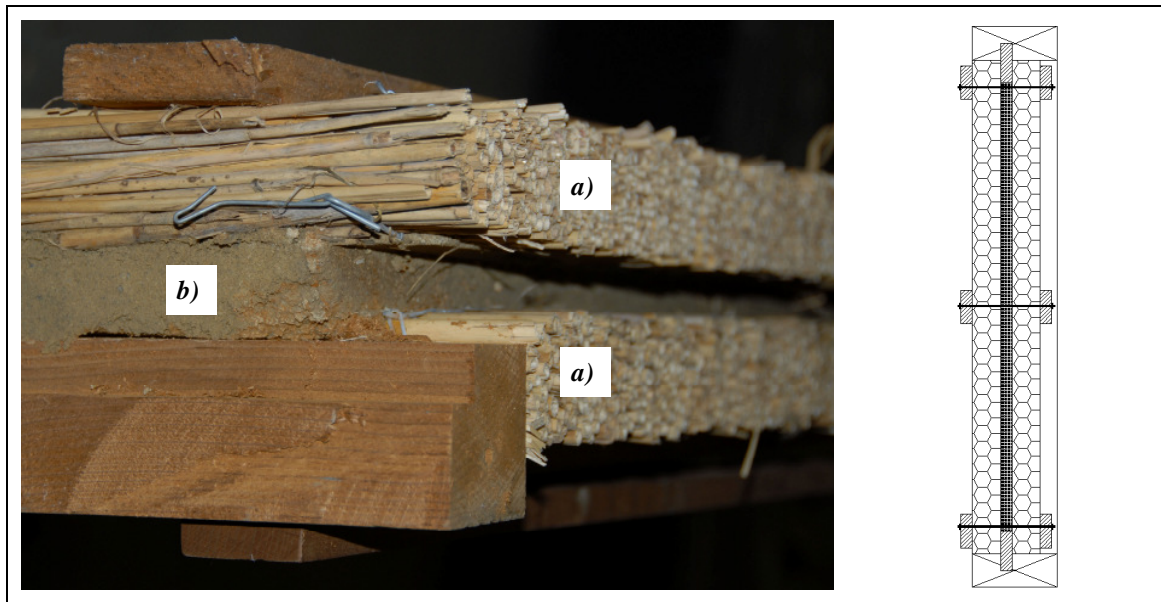


Figure 2: Noise barrier protection system. left: structural layers a) reed, b) clay; right: cross section

ENVIRONMENTAL ASSESSMENT

Life-cycle assessment (LCA) is an adequate method to comprehensively assess the environmental impacts of products and services. An LCA study analyses the entire life cycle of a “functional unit” (i.e. a product or service providing a specific function), considering everything from the extraction of the raw materials to manufacturing, use and disposal of the products involved. It includes all resources consumed and all emissions taking place during all these steps of the product’s life. The International Organization for Standardization (ISO) describes four phases of an LCA in the ISO standard 14040 and 14044. The first step defines the goal and scope of the study, including the definition of a functional unit and the system boundaries. The second step involves the establishment of an inventory of all material flows, emissions and resource consumption. During the third step, these elementary flows are described, characterized and aggregated for different environmental aspects. The last step critically interprets the results and draws final conclusions. An LCA study can be used for product or process improvements, marketing and environmental policy making (Figure 3). An LCA can also aim at comparing different products that have the same functionality.

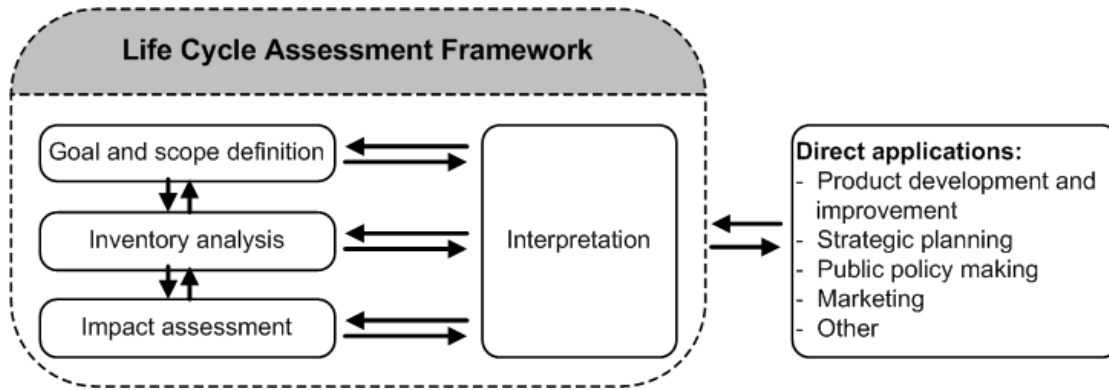


Figure 3: Phases of an LCA according to ISO14040ff.

Goal and Scope

The goal of this LCA study is to evaluate the environmental impact of the previously described noise barrier. The main focus is to identify and quantify the environmental impacts resulting from the production, use and disposal of a noise barrier made from thermally modified timber, and to compare it to conventional barrier elements. This study includes two alternatives; one aluminium element and one acrylic glass element. The study covers the whole life cycle of the barriers and is schematically displayed in Figure 4. The functional unit was defined as one element with the size: 3,960 mm length and 1,000 mm height. The noise barrier elements were assessed for a one-sided noise protection. The elements fit into standard sized steel mounting system type HE160. The mounting system and the foundation were not included in the functional unit, since this is similar for different barrier elements. It is assumed that during the use phase no emissions take place. Data on the thermal treatment and the barrier manufacturing were collected on site. Data for the “forestry”, “sawmill” and the “thermal utilisation” were based on literature. The generic data was based on the ecoinvent Database v2 (ecoinvent Centre 2008). The impact categories used in the present study are: global warming (GWP), ozone depletion (ODP), acidification (AP) and eutrophication potential (EP) (Guinée et al. 2001). Furthermore the cumulative non-renewable energy demand is presented. This LCA study presents preliminary results only. A full LCA study on the noise barrier and alternative barriers is currently under construction, and will be available at the end of the Holiwood project.

Inventory Analysis

Forestry, transport to saw mill and saw mill

The hardwood originates from different regional locations and needs to be transported to the saw mill. At the saw mill the wood is sawn into boards and subsequently dried in a kiln. The following generic data set was used for these processes: “Sawn timber, hardwood, raw, kiln dried, u=10%, at plant/RER”. This dataset is suited for wood from sustainably managed forests.

Reed growing

Due to its good sound absorption properties, reed is used as an inlay. The reed originates from Lake Neusiedl (Neusiedler See) and is collected and dried in Hungary. Since no generic dataset and no production data were available the generic dataset “Hay

extensive, at farm” was modified. Since no cultivation and no fertilization of the reed occur, all air and water emissions were deleted from the generic data set.

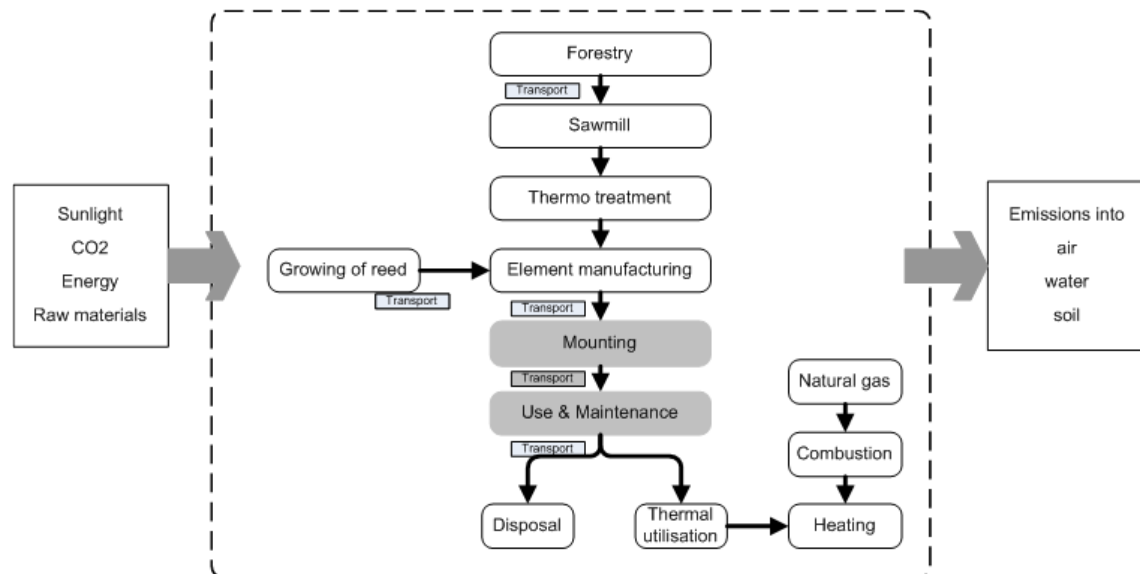


Figure 4: Life cycle of the TMT noise barrier element, including system expansion.

Thermal treatment

The inventory is modelled for an Austrian production site. The heat is produced in a wood chip furnace which is situated on the saw mill premises and is fuelled with waste wood chips from the saw mill; hence no transport of the wood chips is included. The diesel used in the forklift to load the heat chamber is included.

Element manufacturing

The elements are currently manufactured on the saw mill premises by hand since no large scale production is available yet. The reed and *TMT* are put together using steel screws and wires, as well as clay plaster. On the sides of the element a rubber strip is mounted. The aluminium elements are made out of aluminium and rock wool, and a perforation of 26% is assumed. The aluminium is powder coated. On the sides of the element a rubber strip is mounted. The acryl glass elements are made out of acryl glass (PMMA) with a varnish, fitted within an aluminium frame. On the sides of the element a rubber strip is mounted.

End-of-life

After a life span of 20 years the noise barriers are dismantled and disposed of. Thermal utilisation is assumed to be the most likely disposal scenario for the *TMT* element. A generic industrial wood chip furnace (1,000 kW) is assumed. The energy obtained during the thermal utilisation leaves the system boundaries as an additional product. Therefore a system expansion is appropriate. The same amount of thermal energy can also be provided with fossil fuels. The emissions from the extraction and burning of fossil fuels are avoided and therefore subtracted from the system. Here, heat from natural gas in an industrial furnace (low-NO_x, >100 kW) is used for subtraction. The lower heating value of *TMT* is assumed 3,471 MJ/m³, the heating value of reed 1,054 MJ/m³. The density of the *TMT* chips is assumed 189 kg/m³ and of the reed 69.7 kg/m³.

90 % of the steel screws are as well recycled, 10 % is lost during recovery. The aluminium element is recycled, substituting primary aluminium, a loss of 1 % aluminium is assumed. The mineral wool is disposed of in an inert material landfill. The acryl glass is burned in an incineration, where the heat and electricity is utilized. The rubber strip is disposed in a municipal incineration.

Impact assessment

The calculations were conducted with the software SimaPro v7.1 (PRé Consultants 2008). Due to the thermal utilization of the *TMT* and the reed, the global warming potential of the *TMT* barrier element is negative. This indicates that the avoided emissions from fossil fuels outweigh the impacts from the production of *TMT* and the noise barrier element. The same effect is observed for the ozone depletion potential. The acidification and eutrophication potential however, are not outweighed by the system expansion.

Table 1: Preliminary results for the impact assessment

	<i>TMT</i>	Element (without <i>TMT</i>)	End-of-life	Total <i>TMT</i>	Total aluminium	Total acryl glass
GWP (kg CO ₂ -eq.)	22.9	40.9	-110.0	-46.2	152.0	578.0
ODP (kg R11-eq.)	1.9E-6	4.3E-6	-1.4E-5	-7.3E-6	1.1E-5	-2.0E-6
AP (kg SO ₂ -eq.)	0.15	0.19	0.03	0.37	0.53	2.50
EP (kg PO ₄ ²⁻ -eq.)	3.1E-2	2.7E-2	3.0E-2	8.8E-2	5.6E-2	24.7E-2
Non-renewable CED (MJ-eq.)	385	683	-1934	-866	2582	7901

Discussion

The impact assessment of the manufacturing of the noise barrier element shows that between 31% and 53% of the impacts originate from the *TMT*, the rest from the other barrier materials, as well as the transports. Since the CO₂ emissions, resulting from the burning of the *TMT* and reed at the disposal phase, are balanced with the CO₂ uptake from air during the growth of the plants, these emissions do not have an environmental burden. Therefore it can be concluded that *TMT* barriers have an advantageous environmental profile when it comes to global warming and ozone depletion. These results however should be interpreted with care since the project is still ongoing and therefore are preliminary only. A full LCA report, according to ISO 14040ff, will be available at the end of the Holiwood project. The full study will include the mounting system as well as the foundation and compares this barrier to other conventional noise barriers.

CONCLUSIONS

Strength values are lower than those of untreated timber, thus leading to bigger dimensions of the structural parts of the noise barrier elements. The durability of thermally treated hardwoods is sufficient for use in hazard class 3 according to EN 335-1. The biggest limiting factor for structural use of *TMT* is the high loss in dynamic strength. For standard use of *TMT* in structural load bearing elements existing grading systems will have to be adapted. Due to the massive loss in strength the structural use of thermally modified softwoods is strongly limited.

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