XV International Conference on Durability of Building Materials and Components
DBMC 2020, Barcelona
C. Serrat, J.R. Casas and V. Gibert (Eds)

Performance of European Wood Species in Above Ground Situations After 10 Years of Weathering: Evidence of a Positive Impact of Proper Design

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Abstract. *Most of European native wood species used outdoors are expected to last less than 10 years if left untreated and exposed to severe environmental conditions such as high humidity and biological agents. However, the current classification of wood's natural durability based on EN standards does not fully reflect real end-use conditions, often underestimating wood's performance in use. In addition, the importance of design details and the role they play in enhancing service life, especially in the case of outdoor applications, is often neglected. With the aim of evaluating the positive impact of proper design on wood's service life, large-scale experimental devices, manufactured according to different designs (water draining / trapping) from six native wood species, were installed in 2009 in two French cities benefiting from different climatic conditions (oceanic / continental). The results of the evaluation carried out after 10 years of natural weathering demonstrated that (1) significant differences in the ability to withstand decay over time exist depending on the selected design details and the climatic conditions encountered in the experimental fields; (2) high variability in the resistance of non-durable spruce and poplar wood against fungal decay was noticed for each tested design, but with an unexpected high percentage of elements performing very well; (3) the moderately durable heartwood of larch, maritime pine and Douglas fir was mostly unaffected by decay even under severe conditions of exposure to rain (decking modules), suggesting these species may have greater value for outdoor applications without any preservative biocidal treatment than previously assumed.*

Keywords: *Natural Durability, Service Life, Performance, Design, Natural Weathering, Decay.*

1 Introduction

The service life of a wooden structure is the period of time after installation during which it meets the initial performance requirements, such as mechanical strength, and before replacement is needed. This depends on many factors, some being natural and beyond human control, such as wood's inherent characteristics and environmental factors (wind, rain, sun, biological decay agents), and some a result of man's actions, such as design and maintenance.

The majority of European native timber species of economic importance for the building sector are regarded as naturally moderately or poorly durable with regards to biological degradation when used for outdoor applications, such as cladding and decking. In geographical areas where biological risk is high, they are frequently expected to last less than 10 years when left untreated and exposed to severe environmental conditions such as high humidity. As a consequence, in order to ensure long-lasting products, architects tend to choose durable tropical hardwoods or native woods with enhanced durability (modified or preservative treated) rather than moderately durable European wood species whose performance over time is doubtful.

However, the importance of design details and the role they play in enhancing wood's service life, especially in the case of outdoor applications, is often neglected. Indeed, premature fungal degradation of wood is frequently the consequence of inappropriate use, poor design or mistakes made during the installation, generating water traps and thus increasing the wood's moisture content up to a level allowing the initiation of decay.

The performance of wooden structures in terms of service-life relies both on wood's natural durability and on its exposure to weathering and biological risk. Natural durability is beyond our control, but the severity of exposure to environmental parameters can be reduced by good practices such are proper design, proper installation and proper maintenance. The objective of this study is to demonstrate that proper design of wooden structures meant for outdoor use is crucial to providing products whose service life meets the market's needs and the final users' expectations.

2 Experimental Set-up

Large experimental structures were constructed from six wood species, selected for their economic importance for the construction industry and different natural durability against fungal decay according to EN 350 (2016). They mimicked wooden constructions used outdoors above ground: cladding, decking, posts, inclined beams, assemblies, and log house outer walls (Figure 1). In order to compare their performance under different climatic conditions, the test devices were installed in 2009 in the French cities of Bordeaux and Charrey-sur-Saône (oceanic and continental climates, respectively). The full description of the experimental set up is given in Kutnik *et al.*, (2011).

2.1 Selected Timber Species

Douglas fir (*Pseudotsuga menziesii*), maritime pine (*Pinus pinaster*) and larch (*Larix decidua*) are commonly used for manufacturing outdoor structures, mainly for cladding and decking. The natural durability of their heartwood against Basidiomycete decay fungi ranges from moderately (DC 3) to poorly (DC 4) durable (EN 350, 2016), which makes them hardly suitable for use class (UC) 3.2 and UC 4 applications (EN 335, 2013) without any preventative preservative treatment, especially where long service life is expected (> 10 years).

Spruce (*Picea abies*) and poplar (*Populus sp*.) are classified as poorly (DC 4) to non-durable (DC 5) against fungal decay. In practice, they are not used untreated for UC 3.2 and UC 4 applications. In our study spruce and poplar were used as reference non-durable species, expected to decay to some extent over a period of 10 years of exposure to weathering. Different levels of decay were expected depending on the design selected for manufacturing particular experimental devices. European oak (*Quercus robur*), classified as durable (DC 1-2), was used as the reference durable wood species.

2.2 Design Details

Each type of construction comprised both water-trapping and water-draining design details. The results presented in this paper mainly concern the decking modules and the post-to-beam connections, with the design details used for manufacturing them being described in subsequent sections. Since, based on visual inspection only, the remaining construction types (log walls, posts and inclined beams) provided less interesting input, it was decided that they will be the subject of further investigation involving other tools later on.

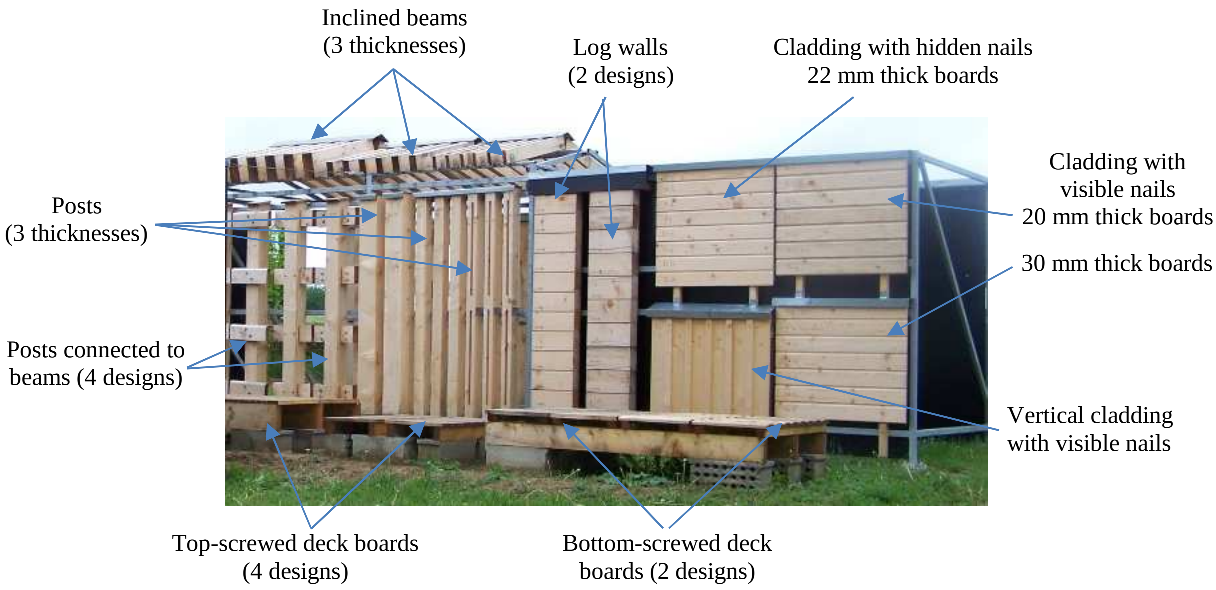

Figure 1. Experimental site in Charrey-sur-Saône, France – examples of devices made from poplar.

2.2.1 Decking Modules

The decking modules were designed to simulate exterior residential decking. They consisted of deck boards fixed on wooden joists, placed on concrete blocks to avoid direct contact with the ground. The four corners of the decking modules were also placed on concrete masonry so that their bases were at least 20 cm above ground (Figure 1). Fifty-centimeter-long boards were cut as much as possible from heartwood, pre-drilled with one or two holes near each end and mounted in two uniformly spaced rows of 5 to 16 replicates on a sub-frame (joists and/or beams) using stainless steel screws.

The modules were manufactured according to designs simulating either UC 3.2 (outdoor unprotected, without permanent water accumulation) or UC 4 (horizontal, above ground, with water accumulation over long periods of time) conditions according to the French FD P 20-651 (2011), thus representing different levels of risk with regard to the probability of fungal decay. The differences between the selected designs were the thickness, width and shape of the deck boards, the way of screwing the boards on the joists beneath (top or bottom screwing) and the typology of the wood-to-wood contact zones (water draining or water-trapping).

Design A, being the most traditional decking design, was expected to represent the worst-case scenario of exposure to water accumulation (on the wood’s surface, on the screws’ top, at the interface between the boards and the joists beneath). Designs B and C employed thicker boards, wider (B) or thinner (C) than design A. Designs D, E and F included different details avoiding water trapping and/or improving water drainage of the deck’s surface and thus were expected to perform better than designs A, B and C.

Six decking modules were constructed from spruce and poplar (one according to each design type). Two modules were constructed from maritime pine, larch, Douglas fir and oak, according to designs A and F, expected to represent respectively the worst and the best case scenario with regard to fungal decay. The construction details are described in Kutnik and Montibus (2019).

2.2.2 *Cladding Units*

Cladding units of 1m x 1m were built according to four different designs, the main differences being the thickness (20 or 30 mm) of the test boards, the way of assembling and screwing them on the battens (tongue and groove boards with visible nails or lap joint boards with hidden nails) and the orientation of the wood's fibers (three horizontal and one vertical cladding) (Figure 1). Sixteen cladding units (8 spruce + 8 poplar) were installed in a setting that either allowed (4 + 4) or prevented (4 + 4) their direct exposure to wind-driven rain. The end-grain of the vertically exposed boards was protected from rainwater by stainless steel sheets.

2.2.3 *Posts Connected to Beams*

Posts were screwed to metallic frames, with end-grain protected from rainwater by stainless steel sheets. Beams were connected to posts using two joining types representative of traditional carpentry: the mortise-and-tenon joint and the cross lap joint. Two innovative types of joints, reducing the wood-to-wood contact zones and allowing for efficient water drainage from the two connected elements, were manufactured as well (Figure 2). All elements were connected using stainless steel fasteners. Sixteen posts (8 spruce + 8 poplar) were installed in a setting that either allowed (4 + 4) or prevented (4 + 4) their direct exposure to wind-driven rain.

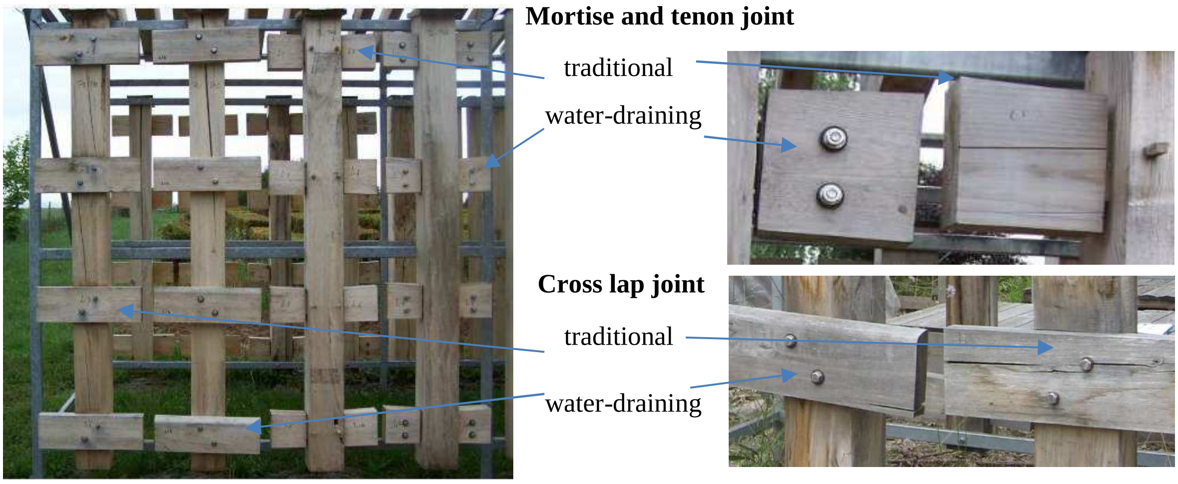

Figure 2. Poplar posts connected to beams in Charrey-sur-Saône, France.

3 Rating of the Fungal Decay

Non-destructive inspections of the deck boards were performed periodically according to a procedure similar to the one recommended in the standard AWPA E25-13 (2014). The decay inspection method consisted of gentle probing of board surfaces, checks and end-grain with a dull metal spatula for signs of softening or cavities. Special attention was paid to areas of high moisture content, discoloration or collapse that were visible on the surface and to areas sounding hollow or dull when tapped with the blunt end of the spatula.

The fungal degradation of exposed wooden elements was evaluated in 2019, after 10 years of exposure to weathering, following a rating scale ranging from “0” (sound, no evidence of fungal attack) to “4” (structural breakdown caused by decay). The rating scale used was adapted from EN 252 (2014) and AWPA E25-13 (2014) (for more details see Kutnik and Montibus, 2019). The scale and the description of the corresponding damage are presented in Table 1.

Table 1. Description of the rating scale used for the assessment of fungal decay.

Rating level	Description of boards' degradation
0 – not degraded	• Little/surface checks • No evidence of decay, no degradation of the fixation points
1 – slight degradation/very limited extent, no immediate impact on boards' usability, no maintenance action required	• Numerous surface checks and/or few deep checks • Maximum 1 fixation point with evidence of decay • Minor softening on end-grain or on sides of checks • Decayed area <2 cm²
2 – moderate decay, no immediate impact on boards' usability, maintenance action might be required within the next few years	• At least 2 fixation points with evidence of decay • Decayed area: max depth 2-3 mm over max 5 cm² OR depth of 5 mm over max 2-3 cm²
3 – severe decay, replacement to be scheduled shortly	• All fixation points decayed OR extensive decay area > 5 cm² and/or > 3 cm³ • Visible fungal activity and/or mycelium and/or fruiting body • Severe decay, likely to seriously affect the loadbearing capacity but not broken when stepped on sharply by a person of moderate weight
4 – failure, replacement needed	• Very severe decay with greater than 50% of a cross section affected • Breakage of the board or severe surface collapse • Failure when stepped on sharply by a person of moderate weight

4 Results of the Inspection Carried Out After 10 Years of Weathering

The cumulative impact of wood's natural durability, exposure conditions and effectiveness of design-based protective measures on the service life of the tested wooden constructions were quantified based on the evaluation of fungal decay. The results presented are those of the evaluation of the decks and the post-to-beams assemblies.

4.1 Assessment of the Decking Modules With Regard to Fungal Decay

The results of the evaluation are presented in Table 2 for each wood species, design type and location ("Bord" for Bordeaux and "Charr" for Charrey-sur-Saône).

The upper surface of the decks manufactured from oak, Douglas fir, larch and maritime pine (the latter in Charrey-sur-Saône only) showed either no or very little visible decay or decay limited to parts of the boards which were assumed to be residual non-durable sapwood. For this reason, the decks were left in place in order to allow future evaluation and only the top side of the boards was rated. After 10 years of weathering, the impact of the selected design details used in the decks manufactured from these four wood species was not measurable yet.

Oak (the durable reference species) resisted fungal deterioration over time, with 14 out of the 16 boards rated "0" for both design A and F in Bordeaux and all 16 in Charrey-sur-Saône rated likewise. Deck boards made from moderately to slightly durable larch and Douglas fir resisted deterioration over time on both test sites, the great majority of deck boards being rated "0" for fungal decay. A few boards reached the decay level of "2" and "3", but this degradation concerned only the residual sapwood parts. Deck boards made from maritime pine resisted degradation in Charrey-sur-Saône to the same extent as larch and Douglas fir, but high variability was observed in Bordeaux (deck boards rated from “0” to “4”). Maritime pine boards comprised a lot of sapwood and this is certainly the main cause of their premature decay.

Table 2. Number of deck boards of each wood species and design type rated 0 to 4.

Wood species	Design type	Location	Number of boards per rating level					Number of boards
			Rating 0	Rating 1	Rating 2	Rating 3	Rating 4	
oak	A	Bord	14	1	1	0	0	16
oak	A	Charr	16	0	0	0	0	16
oak	F	Bord	14	2	0	0	0	16
oak	F	Charr	16	0	0	0	0	16
larch	A	Bord	13	3	0	0	0	16
larch	A	Charr	15	1	0	0	0	16
larch	F	Bord	13	1	2	0	0	16
larch	F	Charr	14	1	0	1	0	16
Douglas fir	A	Bord	10	2	3	1	0	16
Douglas fir	A	Charr	15	1	0	0	0	16
Douglas fir	F	Bord	10	1	2	3	0	16
Douglas fir	F	Charr	14	1	0	1	0	16
maritime pine	A	Bord	6	3	2	4	1	16
maritime pine	A	Charr	13	1	0	2	0	16
maritime pine	F	Bord	4	0	3	4	5	16
maritime pine	F	Charr	15	0	0	1	0	16
spruce	A	Bord	0	2	6	6	2	16
spruce	A	Charr	0	5	8	3	0	16
spruce	B	Bord	0	1	1	8	0	10
spruce	B	Charr	0	0	3	4	5	10
spruce	C	Bord	5	18	6	5	2	36
spruce	C	Charr	0	13	6	14	3	36
spruce	D	Bord	1	5	5	1	4	16
spruce	D	Charr	0	5	5	4	3	16
spruce	E	Bord	7	4	3	1	0	16
spruce	E	Charr	2	10	2	0	2	16
spruce	F	Bord	5	5	1	1	4	16
spruce	F	Charr	9	5	0	2	2	18
poplar	A	Bord	0	0	8	5	3	16
poplar	A	Charr	0	12	2	1	1	16
poplar	B	Bord	0	1	4	5	0	10
poplar	B	Charr	0	10	1	1	0	10
poplar	C	Bord	0	7	16	7	2	36
poplar	C	Charr	0	16	11	9	0	36
poplar	D	Bord	0	0	6	7	3	16
poplar	D	Charr	0	10	3	3	0	16
poplar	E	Bord	0	4	6	5	1	16
poplar	E	Charr	0	11	4	0	1	16
poplar	F	Bord	0	4	6	5	1	16
poplar	F	Charr	0	6	6	2	2	16
Bordeaux/Charrey: dark orange/green colour = highest number of decks with the same rating; light orange/green colour = dispersion of ratings over the deck boards								

Non-durable poplar and spruce decks were dismantled and the boards were individually rated for fungal decay. High variability was recorded in the extent of fungal degradation depending on the tested design and exposure site.

Spruce bottom-screwed deck boards (design types E and F) were significantly less decayed (high number of boards with no - rating “0” - or very little - rating “1” - decay) than top-screwed ones, except boards assembled according to design C (5 cm wide, 1 screw at each end). These boards showed high variability in their resistance to fungal decay and better overall performance than types A, B and D, especially in Bordeaux. The general trend is that decks installed in Bordeaux were slightly less decayed than in Charrey-sur-Saône.

Poplar deck boards were significantly less decayed in Charrey-sur-Saône than in Bordeaux. However, the impact of the design was less obvious than in the case of spruce. Similar performance was found for all decks irrespectively of their design in Charrey-sur-Saône and slightly better performance of bottom-screwed boards was observed in Bordeaux.

4.2 Post–to-Beams Assemblies

The assemblies evaluated on the test devices made from oak, larch, Douglas fir and maritime pine were all found sound after 10 years of exposure, irrespective of the tested design.

Spruce and poplar wood mortise-and-tenon and cross lap assemblies constructed according to water-draining designs were all sound in both test sites, irrespective of whether they were or were not directly exposed to wind-driven rain. Assemblies constructed according to water-trapping designs were decayed to different extent, depending on the wood species (spruce was less decayed than poplar) and test site (test devices installed in Charrey-sur-Saône were less decayed than those in Bordeaux). Decay fungi degraded the wood-to-wood contact zones of both elements (posts and elements connected to them) leading in many cases to the breakdown of the assembly. Figure 3 shows that mortise-and-tenon (1) and cross lap (2) assemblies were either sound, when constructed according to water-draining design (WD) or extensively decayed by fungi, when constructed according to water-trapping design (WT).

Several wooden elements connected to the posts were affected by superficial decay (larch, maritime pine, poplar and spruce), located mostly on their upper part and/or in sapwood parts.

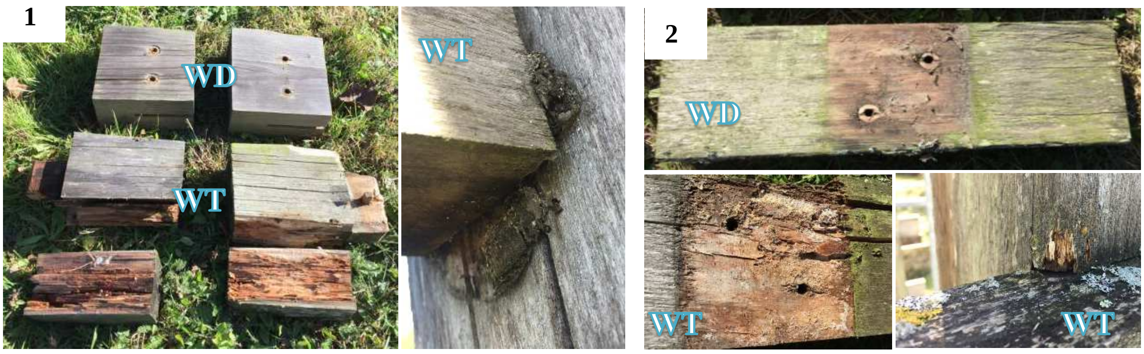

Figure 3. Poplar posts connected to beams in Charrey-sur-Saône, France.

13 Conclusions

- Significant differences in the ability of wood to withstand decay over time were observed depending on the selected design details used and the surrounding climatic conditions, especially in the case of non-durable spruce and poplar wood;
- The continental climate was less favorable to decay fungi than the oceanic one;
- A positive effect of the water draining designs was demonstrated for decks and assemblies made from non-durable spruce and poplar wood, with fewer elements being affected by fungal decay and lesser extent of decay;
- The moderately durable heartwood of larch, maritime pine and Douglas fir was unaffected by decay, even under severe conditions of exposure to rain and water accumulation (decking). This suggests that these wood species could be used without any preservative treatment, provided the sapwood has been removed, for manufacturing outdoor structures whose service life could by far exceed 10 years;
- Wooden structures made of non-durable spruce and poplar showed high variability in terms of resistance against fungal decay, but with a high percentage of elements being still sound or below their limit state of use after 10 years;
- European standards provide keys to proper selection of timber species (EN 350:2016), understanding of the biological risks associated with their use (EN 335:2013) and proper treatment where necessary (EN 599-1:2014). However, given the diversity of conditions under which wood may be in service, there is no direct, simple and reliable method to predict service life under real-use conditions based on durability classification alone. To accomplish this more reliable service life prediction tools need to be developed.

Acknowledgements

We thank “Région Bourgogne - Franche Comté” for their financial support for this study.

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