FINAL SUMMARY OF HOUT BAY HOUSE RESEARCH PROJECT

Results of research focused on degradation of wood

in conditions of South Africa

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1 INTRODUCTION

Hout Bay House research project is focused on exploring an unique type of timber construction in South Africa. It is an international research project which uses ecological and sustainable materials. The aim of the project is to find an optimal form of timber construction in South Africa and to awaken the interest and trust in these modern types of buildings.

Hout Bay House is located in Western Cape which is known for coastal and windy conditions. The design of house uses the newest technologies in the wood industry with the respect to basic construction solution increasing the durability of wood and whole service life of a building. The construction of the house is made of the lower brick and mortar part and upper wooden part (Figure 1). For the load bearing wall construction, the 84 mm thick NOVATOP solid wood panels from cross laminated spruce timber were used. The walls were insulated by wood fibre insulation Pavatex (with bulk density 145 kg/m^3) with the thickness of 80 mm (west façade) and 120 mm. The external layer is created by the wooden facade (Siberian larch and thermally modified pine) held by the spruce grid with ventilated air gap with the thickness of 60 and 100 mm, respectively. In some parts of the interior the NOVATOP layer is covered by Fermacell gypsum-fibre boards. The roof consists of open NOVATOP elements filled with thermal insulation with roof overhangs and covered by metal sheets.

Figure 1: Hout Bay House and its construction

Bedrooms are located on north side while the kitchen and living room are on south side. There is no heating or air-conditioning in the house. Windows are double-glazed with high quality which ensures the whole air tightness of the house – together with complex NOVATOP structure.

The research part was dealing with different topics.

- Evaluation of thermal properties and determination of the ideal thickness of insulation and thermal comfort of the house.
- Surface degradation of treated and untreated wood in the specific conditions of South Africa.

This paper summarizes the results obtained in the research part focused on wood degradation in conditions of South Africa between the years 2015-2019.

2 RESERCH PART: SURFACE DEGRADATION OF WOOD

Hout Bay House research project is focused on exploring unique type of timber construction located in Western Cape. The main objective is to evaluate wood degradation after exposure to weathering process in specific climatic conditions of South Africa and compare the performance of treated and untreated wood.

Nowadays, the trend of ecological building is becoming more progressive. Wood as a renewable material is noted for some obvious advantages connected with its nature origin respecting the ecological and sustainable development. The amount of wood used both in the interior and exterior is increasing day by day with respect to the ecological aspect. The wooden structures and elements are more often treated with natural-based surface treatments or even untreated.

When the wood is used in the exterior, there are some major issues which should be followed to reduce the effect of weathering on wood degradation. First, it is recommended to use wood materials with higher natural durability in accordance with EN 350. Natural durability is given mainly by content of extractives, not by density of wood. Second, a proper construction solution is required (optimal shape of wood element, covering the end parts, roof overhangs, ventilation, distance from the ground etc.). Third, the surface treatment can be used to prolong the service life of wood. In the case of respecting above mentioned steps, the degradation affects only the surface layers of wood, which can be manifested by the change of colour, followed by a formation of cracks and increased roughness of the samples. The most significant weathering factors influencing the rate of degradation are solar radiation and water, acting synergistically. However, there are other factors which contribute to surface degradation such as temperature, dust particles, acid rain and air flow. Mainly the UV light initiates photochemical reactions, which cause decomposition of lignin, extractives and partly even hemicellulose. Degraded compounds are leached from the wood by water. As the result, wood changes colour, some species turns yellow or brown, eventually, they turn into grey, which is often caused by growth of fungi and moulds and by the dust particles in air which penetrate to the porous structure of wood. After leaching of UV degradation products, underlying cell layers are exposed and further eroded. Erosion is more rapid in the less dense early-wood than in latewood, which leads to an uneven and rougher surface. Formation of checks, split and cracks caused by moisture and temperature changes also leads to tangible surface roughness.

2.1 Wood exposed to weathering at HBH

Outdoor wood constructions react to the weather and its changes. For their proper use, it is necessary to respect previously mentioned steps (use of durable wood species, proper construction solution, use of surface protection). The Siberian larch wood and thermally modified pine, in European conditions considered as durable, were selected for the façade cladding and terrace decking at Hout Bay House (Figure 2). Larch has high resistance to climatic factors but without a suitable surface treatment it tends to turn grey and crack. Thermally modified pine wood has been produced by controlled process during which was the wood being exposed to high temperatures in range of 185-215 °C. This material is generally considered to be very durable with regard to given climatic conditions and does not undergo substantial dimensional changes. It is also noted for increased resistance to rotting and cracking.

Figure 2: Test samples (from left: thermally modified pine untreated and treated, Siberian larch untreated and treated)

2.2 Methodology

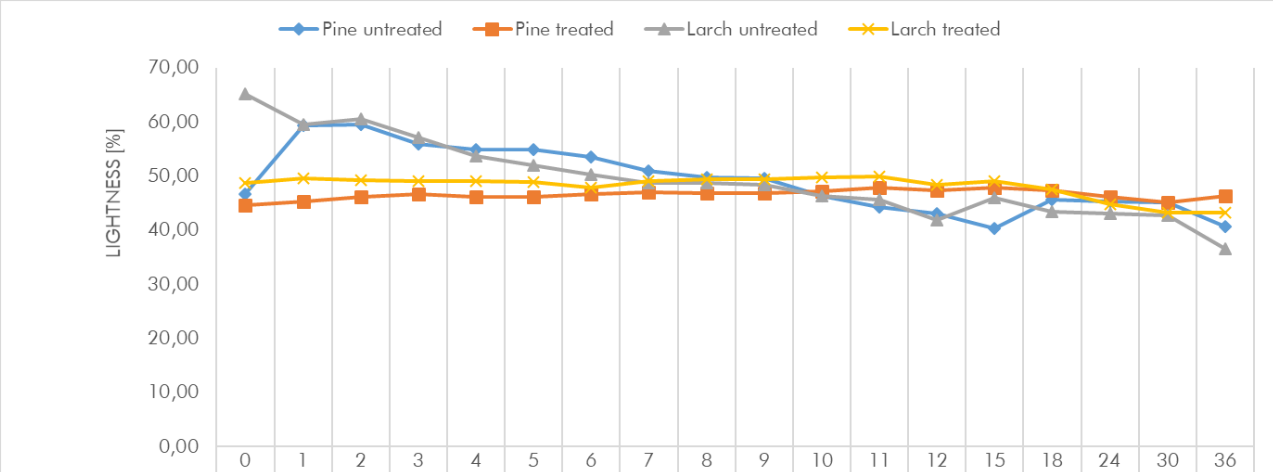
The test samples were prepared from selected wood species, one part of them was left untreated, the other part was treated with two layers of natural oil wood stain UV OSMO. Prepared samples were exposed to natural weathering in special stands facing north in the inclination of 45° according to European standards dealing with testing of coatings (this angle of exposure makes the degradation faster than in the case of wooden façade cladding, but slower than in the case of terrace decking). The test samples were cut off from the exposed elements and evaluated on the basis of change of colour, gloss, roughness, wettability and other visual properties during three years of exposure, monthly in the first year of the research, then in longer periods (Figure 3). In addition, the degradation process of real wooden treated and untreated façade and terrace at HBH was also regularly observed and evaluated.

Figure 3: The test samples marking and measurements using spectrophotometer and profilometer (from left)

2.3 The colour changes during weathering

The colour reflects the basic chemical composition of wood. If the wood contains a high amount of extractives, the chemical processes of the colour changes quickly take place. The change of colour is mainly affected by UV light and rainwater. The colour was measured by the device spectrophotometer which records the basic colour parameters L*a*b* in CIELab colour space (Figure 4, Figure 5, Figure 6):

- Parameter L* – LIGHTNESS from black (0) to white (100)

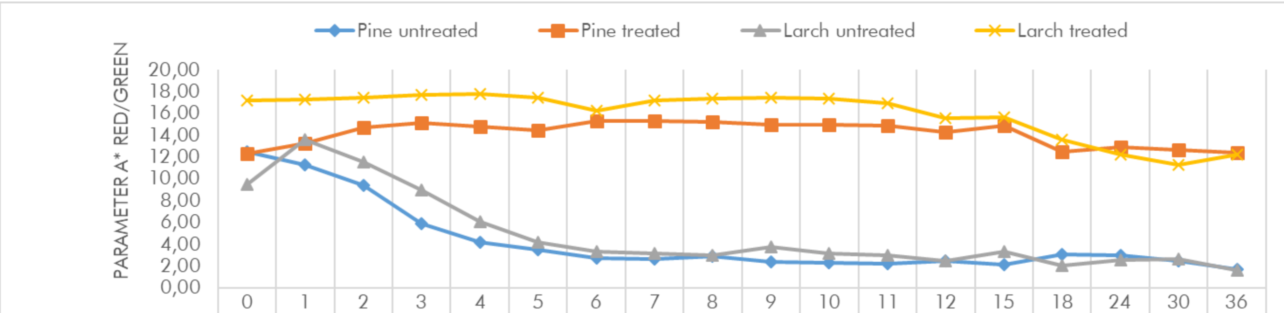


	0	1	2	3	4	5	6	7	8	9	10	11	12	15	18	24	30	36
Pine untreated	46,59	59,31	59,49	55,94	54,91	54,81	53,56	50,90	49,64	49,54	46,22	44,24	42,97	40,23	45,60	45,20	45,14	40,56
Pine treated	44,55	45,23	46,13	46,64	46,07	46,05	46,57	46,90	46,84	46,85	47,06	47,84	47,34	47,84	47,37	46,15	45,09	46,35
Larch untreated	65,22	59,57	60,58	57,05	53,68	51,91	50,22	48,75	48,61	48,36	46,36	45,63	41,82	45,92	43,44	43,01	42,66	36,54
Larch treated	48,76	49,49	49,22	49,11	49,09	48,89	47,85	49,07	49,46	49,36	49,64	49,89	48,40	49,08	47,53	44,76	43,16	43,25

PERIOD OF WEATHERING IN MONTHS

Figure 4: Change of lightness parameter during weathering

- Parameter a* – shades from red (+60) to green (-60)

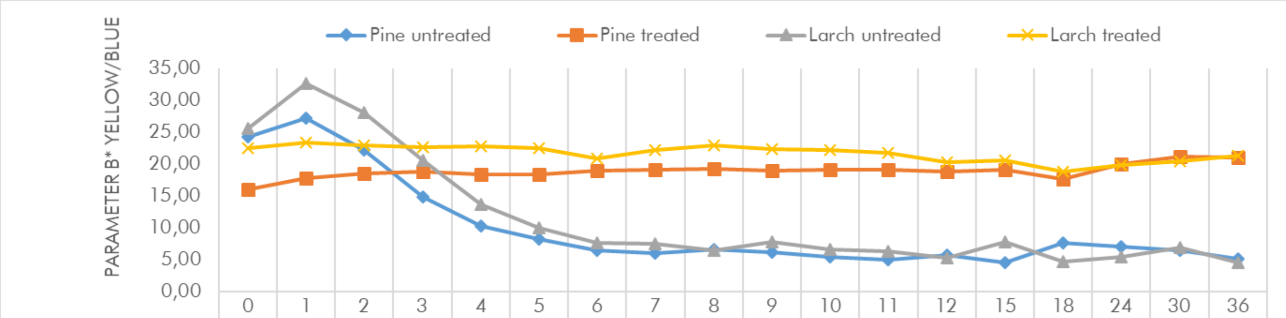


	0	1	2	3	4	5	6	7	8	9	10	11	12	15	18	24	30	36
Pine untreated	12,46	11,31	9,37	5,92	4,14	3,46	2,69	2,60	2,86	2,37	2,25	2,17	2,45	2,08	3,09	2,98	2,43	1,69
Pine treated	12,31	13,26	14,68	15,15	14,79	14,43	15,29	15,35	15,20	14,99	14,95	14,84	14,27	14,84	12,49	12,87	12,63	12,39
Larch untreated	9,44	13,59	11,53	8,97	6,06	4,21	3,33	3,17	2,98	3,70	3,12	3,01	2,49	3,36	1,99	2,54	2,64	1,63
Larch treated	17,16	17,30	17,45	17,68	17,77	17,45	16,29	17,16	17,39	17,43	17,34	16,96	15,58	15,62	13,57	12,21	11,31	12,21

PERIOD OF WEATHERING IN MONTHS

Figure 5: Change of a* parameter during weathering

› Parameter b* – shades from yellow (+60) to blue (-60)



	0	1	2	3	4	5	6	7	8	9	10	11	12	15	18	24	30	36
Pine untreated	24,27	27,15	22,21	14,85	10,21	8,17	6,46	5,93	6,56	6,09	5,32	4,89	5,74	4,52	7,55	7,05	6,37	5,12
Pine treated	15,93	17,82	18,41	18,83	18,35	18,35	18,97	19,07	19,27	18,94	19,08	19,07	18,75	19,07	17,53	19,98	21,10	21,05
Larch untreated	25,55	32,54	27,97	20,50	13,58	9,89	7,57	7,41	6,46	7,76	6,61	6,21	5,17	7,81	4,69	5,32	6,86	4,56
Larch treated	22,51	23,32	22,85	22,66	22,79	22,46	20,83	22,13	22,82	22,25	22,14	21,76	20,22	20,61	18,84	19,76	20,38	21,26

PERIOD OF WEATHERING IN MONTHS

Figure 6: Change of b* parameter during weathering

The results confirmed that in the early stages of weathering, dark wood tends to become light and light wood becomes dark according to lightness parameter values (Figure 4). The values a* and b* of untreated samples followed a similar trend shown in previous studies, increased at the beginning of weathering and then decreased in the case of untreated samples (Figure 5, Figure 6). The changes in a* values are determined mainly by the changes of the chromophore groups in extractives. The initial increase in b* values indicates the degradation of lignin. The final decrease of yellowness of untreated samples may be attributed to leaching of decomposed lignin and extractives by water. Overall, the colour parameters of treated wood had more stable results without any important fluctuations in comparison with untreated wood.

The total colour difference was then calculated from the colour parameters using the formula:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Where:

L* is the lightness from 100 (white) to 0 (black),

a* is the chromaticity coordinate from -60 (green) to + 60 (red),

b* is the other chromaticity coordinate from -60 (blue) to +60 (yellow),

ΔL*, Δa*, and Δb* represent the differences between L*, a*, b* values before and after weathering.

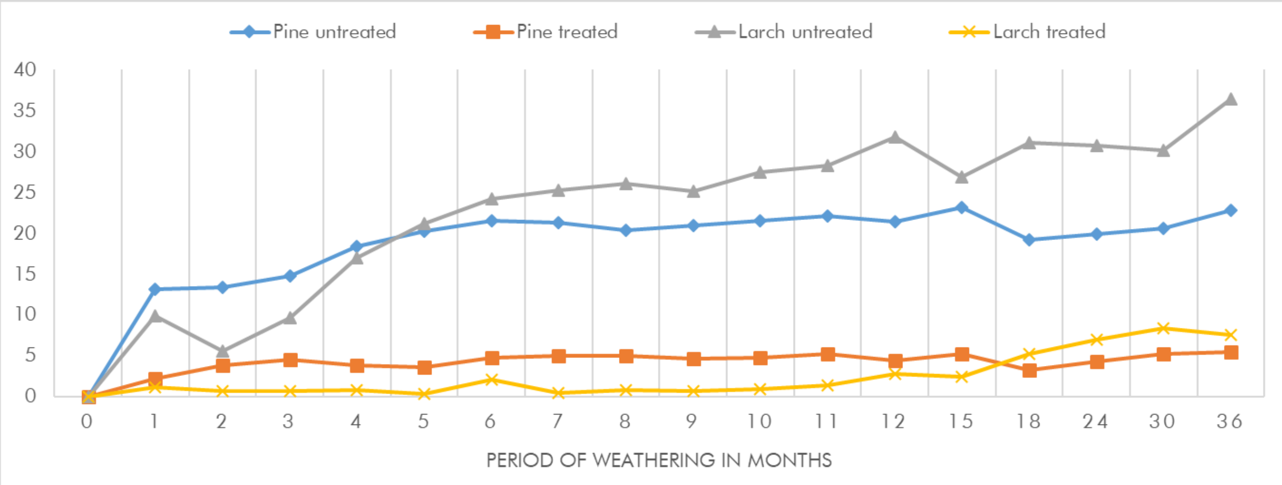


Figure 7: Total colour difference of tested samples during weathering

Quick evaluation of the colour difference using the following standardized table:

Range of values	Degree of discolouration
0,2 < ΔE*	invisible colour difference
0,2 < ΔE* < 2	low colour difference
2 < ΔE* < 3	colour change visible with the high quality filter
3 < ΔE* < 6	colour change visible with the medium quality filter
6 < ΔE* < 12	high colour differences
ΔE* > 12	different colour

Table 1: Classification of colour changes

The graph shows a trend when surface treated samples showed significantly lower colour changes and stable results during 36 months of outdoor exposure (Figure 7). On the contrary, high colour changes were observed even after 1 month of exposure on the surface of untreated wood (both thermally modified pine and Siberian larch). The total colour difference of thermally modified pine increased during exposure. Regarding the untreated Siberian larch, it is possible to observe the trend of large increase in the colour difference after the first month and the drop after other two months. This can be due to the degradation of lignin and extractives caused especially by UV radiation. Thus, disturbed photo-degradation products are washed out from the wood surface and significantly affect the colour change, the colour turns yellow first, then gradually darkens and turns grey. The overall lowest colour difference was observed for treated samples – colour changes visible with the medium quality filter (Table 1), the highest for untreated larch after 36 months of weathering – different colour according to Table 1. Generally, the total colour difference of all treated and untreated samples increased with increasing exposure period in natural weathering.

2.4 The surface roughness changes during weathering

The surface roughness of wood is mainly caused by leaching of UV degradation products and exposed and eroded underlying cell layers and erosion. The surface roughness parameter – Ra (average roughness value) – was measured by the contact profilometer during weathering process.

› Average roughness value – Ra [μm]

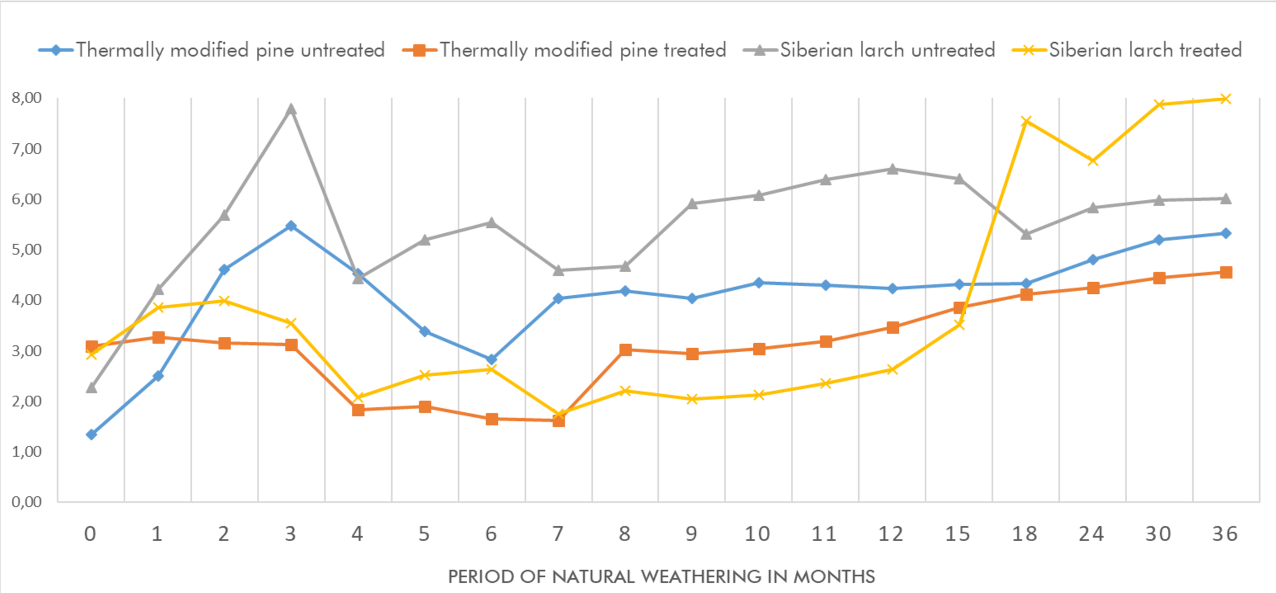


Figure 8: Change of roughness during weathering

The treated samples show a comparable stable results during the 15 months of exposure (Figure 8). After 15 months of exposure, the surface treatment started to degrade. It is obvious from the increased roughness value after this period of weathering, especially for the coating applied on Siberian Larch, which was more degraded in comparison with treated pine. For untreated wood species a high increase in surface roughness can be observed mainly in the beginning of weathering. This trend can be explained by leaching of the products of photo-degradation reactions (lignin, extractives, as well as hemicellulose), which can lead to the tearing of cellulose fibres exposed on the wood surface. The arisen degraded surface is later filled with dust particles and decomposed products which leads to greying and smoother surface. The little fluctuations are rather caused by variability of wood than any significant trend.

2.5 The change of surface wettability during weathering

This graph shows a change of surface wetting during exposure – which express the ability to absorb water (Figure 9). In the case of untreated samples the full wettability of surface is observed already after 18 months of weathering. The treated samples showed decreasing trend of surface wettability related to degradation of coatings themselves. However, after 36 months of weathering, they still maintain relatively good wettability.

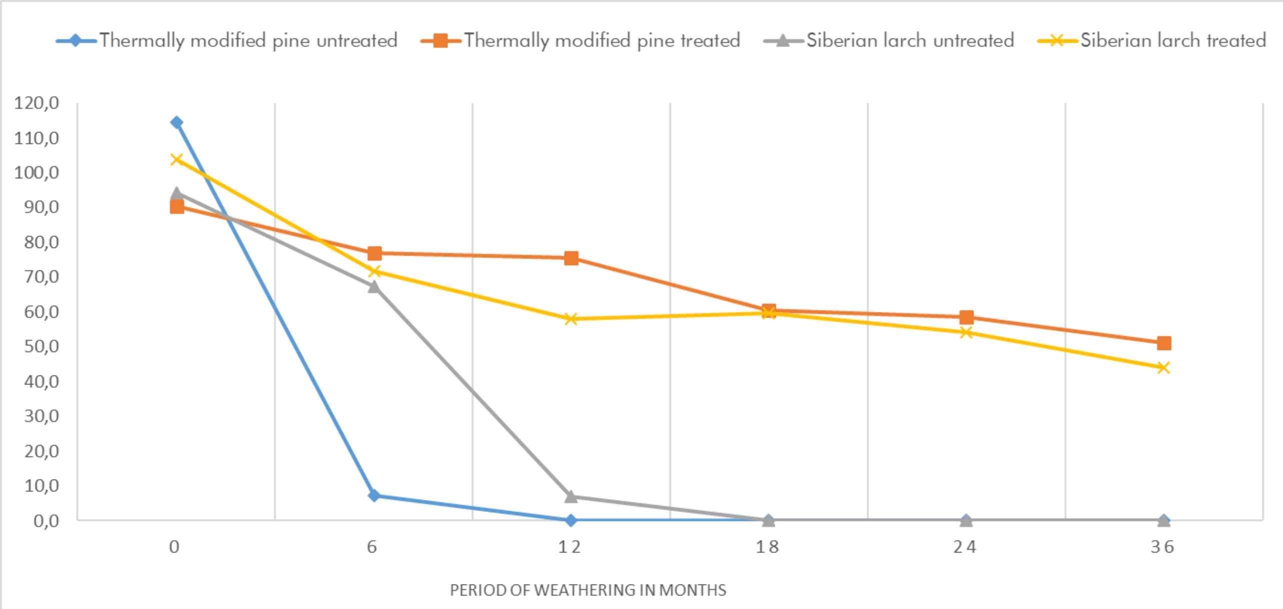
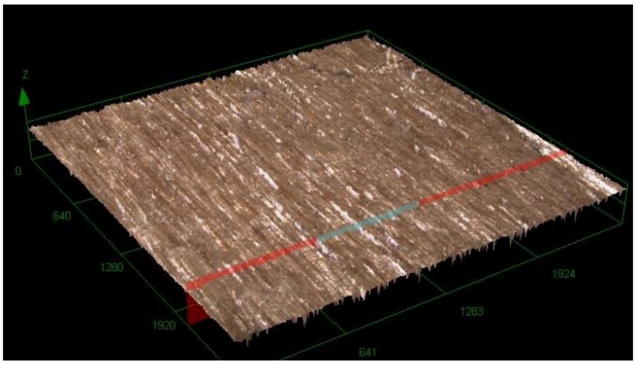


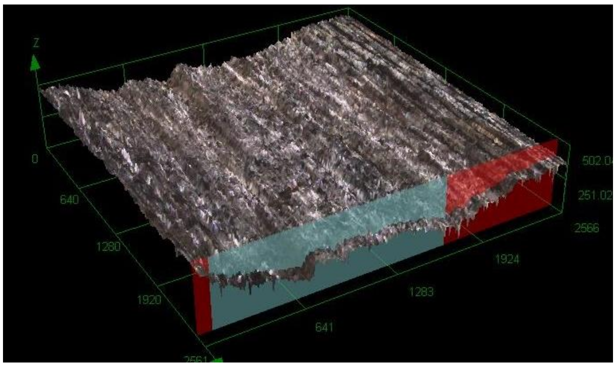
Figure 9: Change of wettability during weathering

2.6 Laser scanning microscopy

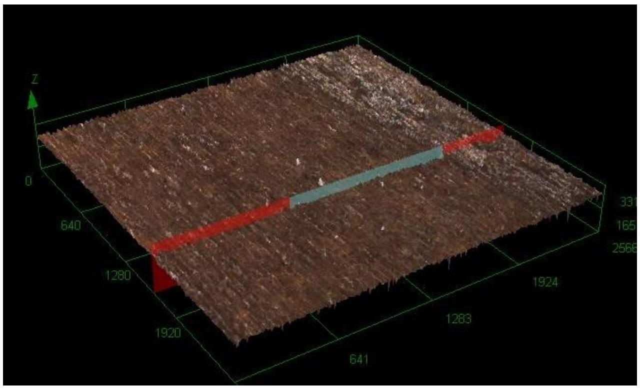
The laser scanning microscopy revealed visible greying of untreated wood caused by weathering, dust settling and formation of surface mould (Figure 10). Also degradation of surface treatment itself applied both on thermally modified pine and Siberian larch (flaking, chalking etc.) after 18 months of exposure was observed. In the case of treated Siberian larch, the degradation of coating is more significant. That was already proved by the evaluation of roughness change.

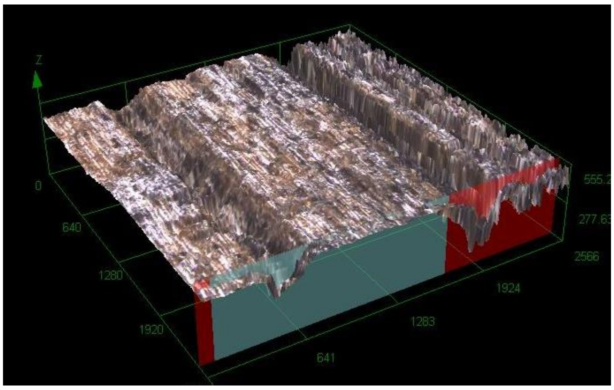
Untreated Siberian larch before (left) and after 18 months of weathering (right)



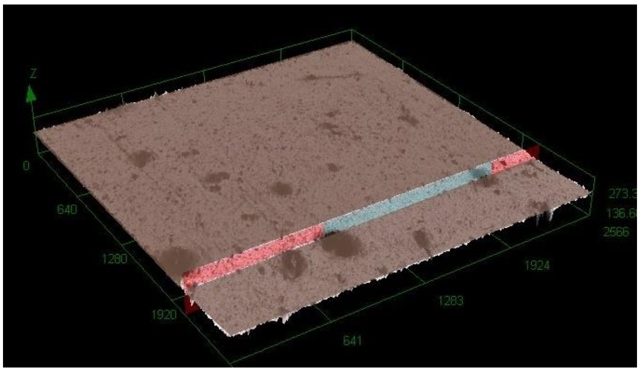


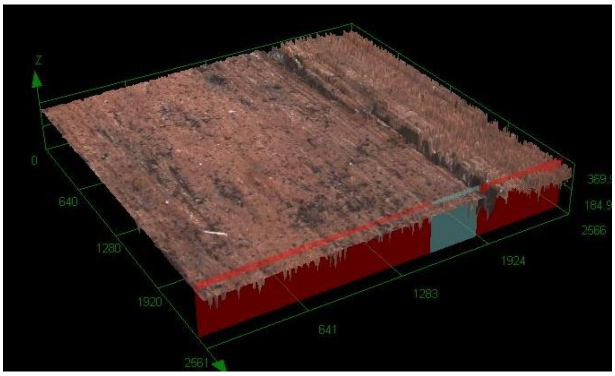
Untreated thermally modified pine before (left) and after 18 months of weathering (right)



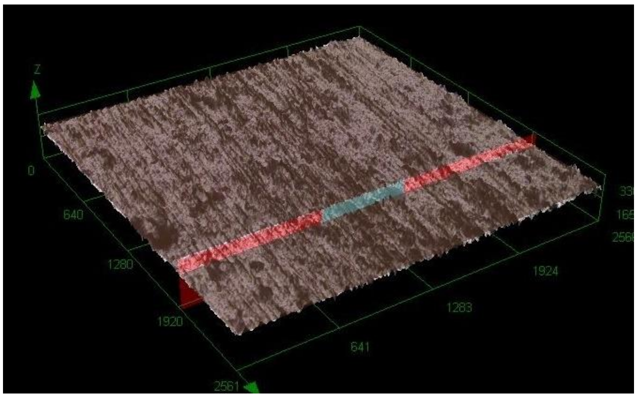


Treated Siberian larch before (left) and after 18 months of weathering (right)





Treated thermally modified pine before (left) and after 18 months of weathering (right)



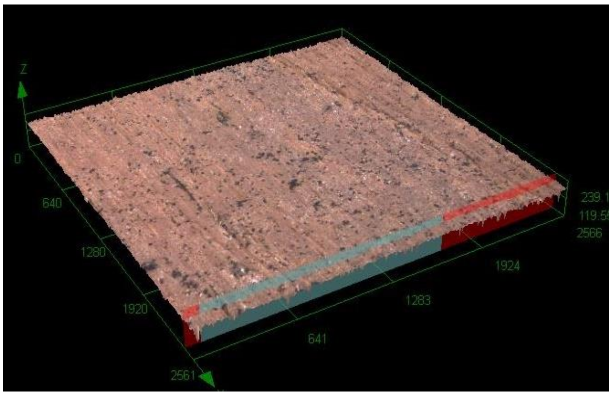


Figure 10: Laser scanning microscopy of samples before and after weathering

2.7 The visual appearance of the test samples

The samples were evaluated also visually (Figure 11). The visual evaluation basically confirmed the measured colour and roughness values. The high colour changes of untreated wood are visible already after 1 month of weathering. The greying is obvious approximately after 4 months of weathering of untreated samples. The formation of cracks which basically ran in the direction of wood fibres was observed on untreated samples during weathering. The degradation of coating started approximately after 12 months of exposure and led to the final peeling and cracking of applied layer, which was more obvious in the case of treated Siberian larch.

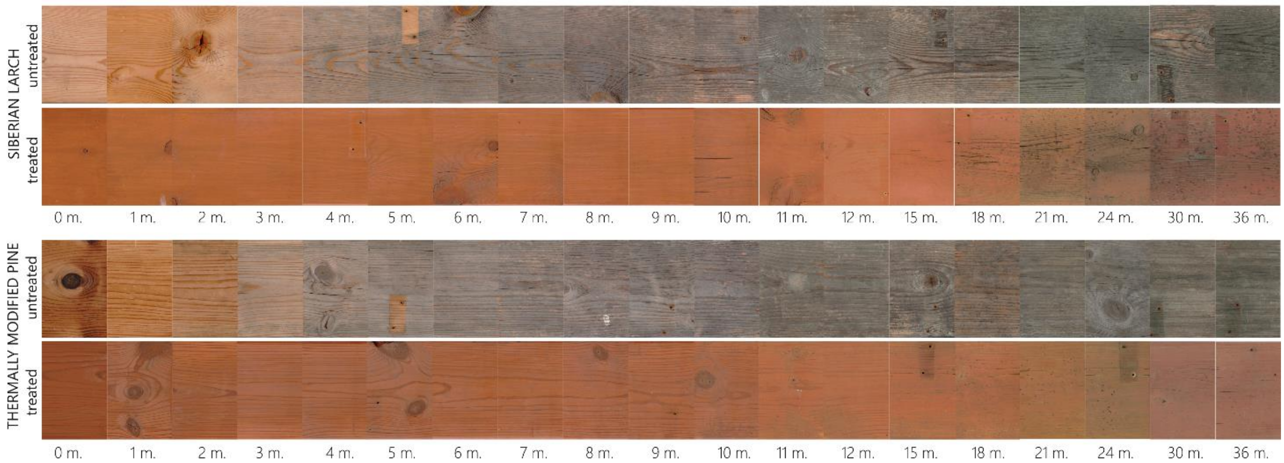
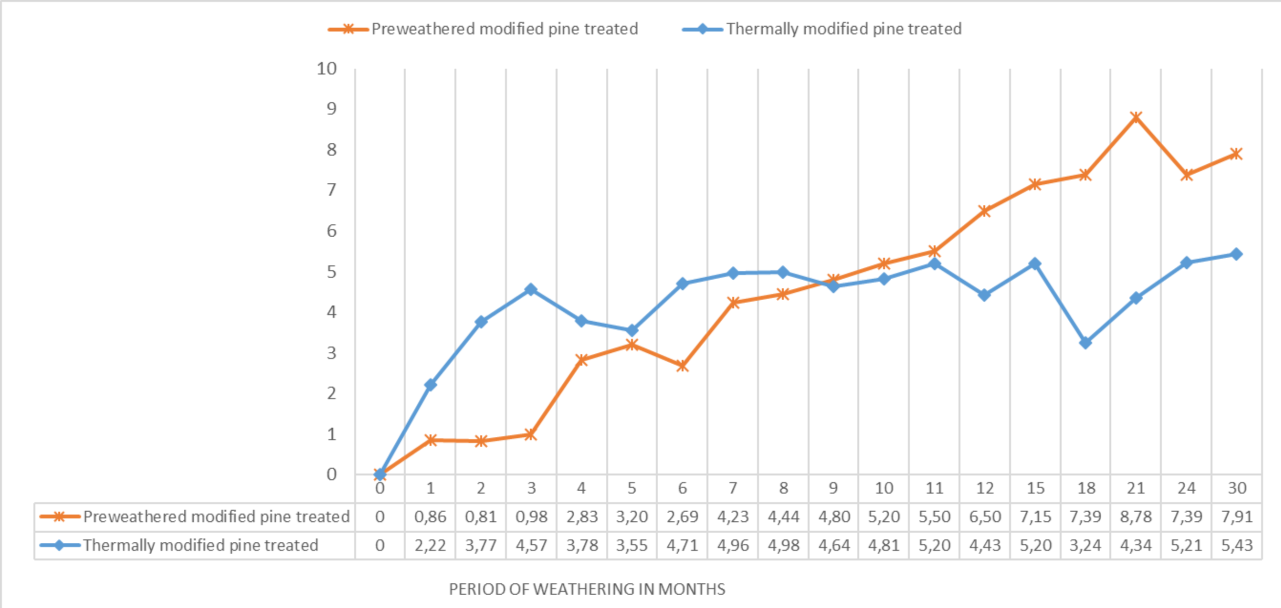


Figure 11: The appearance of test samples during 0 – 36 months of natural weathering (from the top line: Siberian larch untreated and treated, thermally modified pine untreated and treated).

2.8 The performance of pre-weathered thermally modified pine

In practice it can happen that wood in constructions has been weathered prior to application of a finish for some time. Some studies show the better performance of that pre-weathered wood in exterior. For the closer investigation of properties of wood in conditions in South Africa, the pine, which was pre-weathered for 1 month before application of coating, was exposed to natural weathering and regularly evaluated as the rest of the samples in previous experiment.



	0	1	2	3	4	5	6	7	8	9	10	11	12	15	18	21	24	30
Preweathered modified pine treated	0	0,86	0,81	0,98	2,83	3,20	2,69	4,23	4,44	4,80	5,20	5,50	6,50	7,15	7,39	8,78	7,39	7,91
Thermally modified pine treated	0	2,22	3,77	4,57	3,78	3,55	4,71	4,96	4,98	4,64	4,81	5,20	4,43	5,20	3,24	4,34	5,21	5,43

Figure 12: Total colour difference of thermally modified pine (pre-weathered before application of coating and standard) during 30 months of exposure

The graph above shows the total colour difference of pre-weathered thermally modified treated pine in comparison with standard application of coating (Figure 12). We can observe the slower degradation of pre-weathered pine in the initial phase of weathering. After 1 year of outdoor exposure, the pre-weathered pine showed higher colour changes increasing with longer exposure.

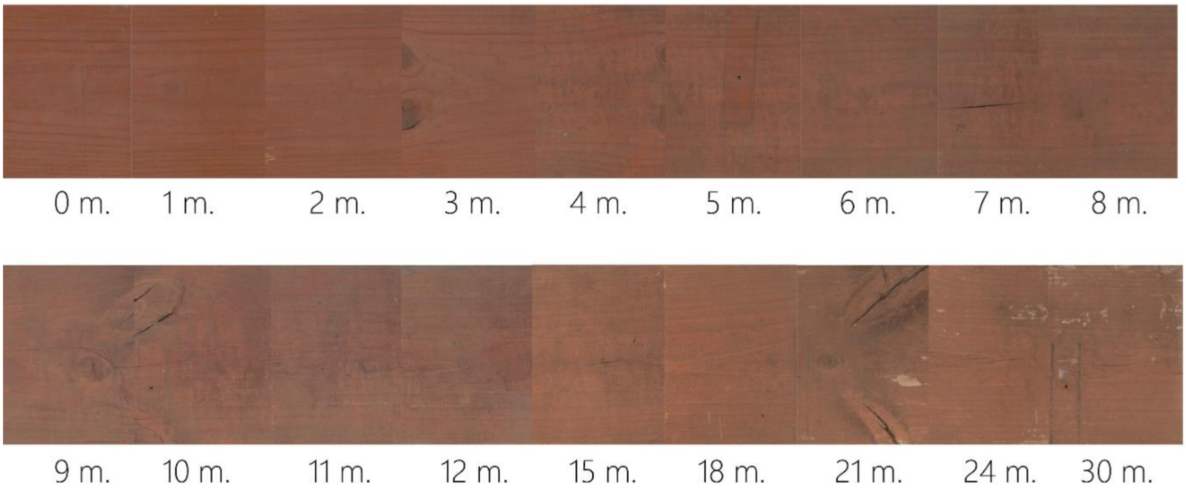


Figure 13: Visual appearance of pre-weathered pine during 0-30 months of weathering

From the evaluation of visual appearance of pre-weathered pine during 0-30 months of weathering (Figure 13), the gradual wood degradation of coatings can be observed. The coating started to degrade basically after 12 months of exposure, the peeling started approximately after 18 months of natural weathering. The total colour changes were higher in the comparison with the samples which were not pre-weathered. From that point, the initial pre-weathering did not improve the wood properties associated with coating application and weathering.

2.9 Visual appearance of wood constructions at HBH

Visual appearance of wood constructions (façade cladding and terrace decking) in the case of Hout Bay House was evaluated (Figure 14). The façade with untreated cladding from Siberian larch and untreated thermally modified pine degrades unequally, since the profiles cover each other and the rain reaches only the lower parts of profiles (Figure 15, Figure 16). Also the effect of roof overhangs is visible – wood under it turned yellow, not grey, as a result of solar radiation effect. Every protrusion causes unequal discolouration. It is not a mistake of a construction or material, but we have to consider that when we design untreated façade. In the case of treated façade, there is also a change of colour which is more apparent in the lower parts of façade – as an effect of roof overhangs. The surface is significantly less glossy and cracks started to appear. The terrace decking is significantly more exposed to weathering than cladding. The untreated terrace is grey and rough after 30 months of weathering. It degraded equally. But once this grey surface is formed, further degradation is slow to develop. We can conclude from the experiments done, that the Siberian larch tends to be more susceptible to cracking than thermally modified pine in the case of wood decking and it has a tendency to increased formation of splinters.

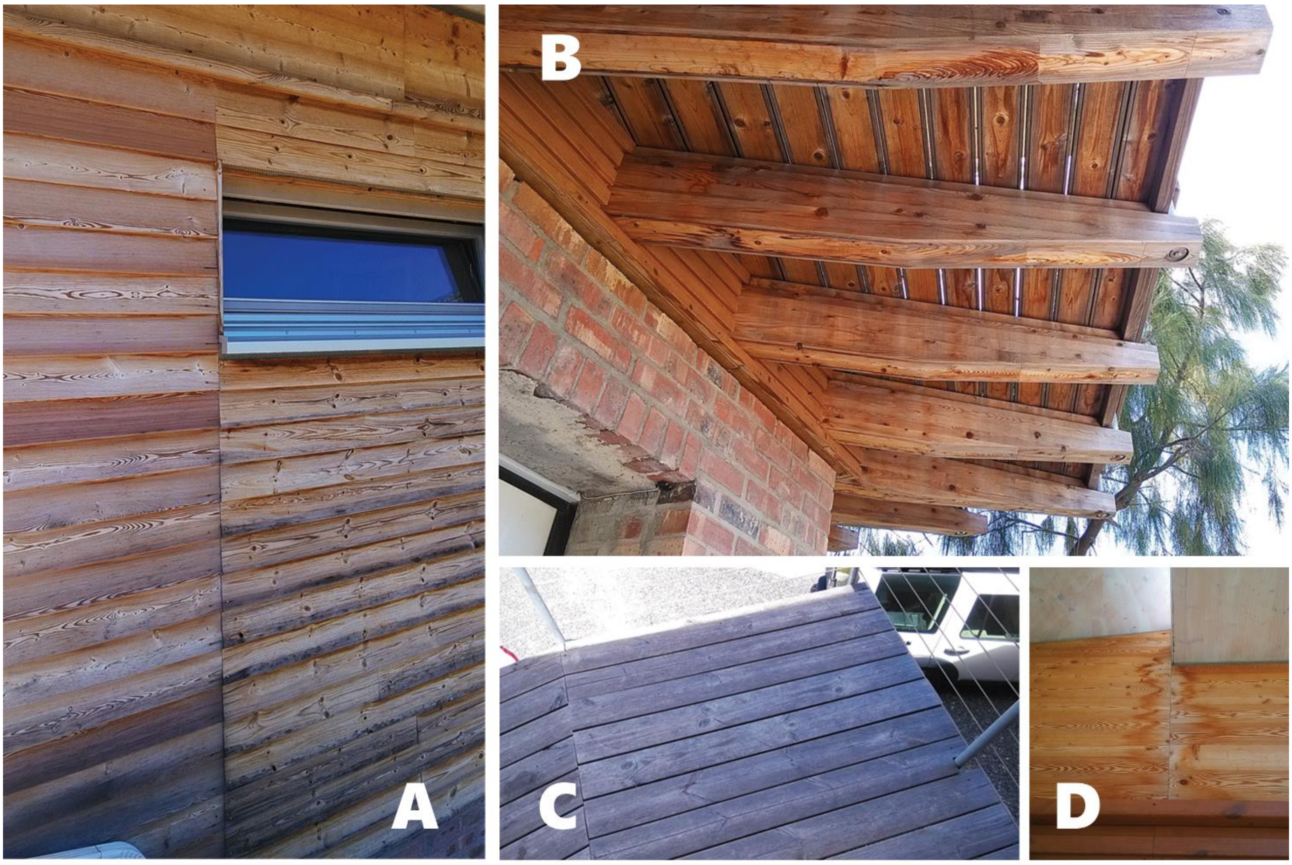


Figure 14: The appearance of wood constructions after 30 months of weathering: visual signs of wood degradation (degraded untreated wood untreated façade with unequal discolouration (A), discolouration and leaching of untreated larch (B), greying of terrace from untreated thermally modified pine (C), leaching of lignin and extractives by water (D)).

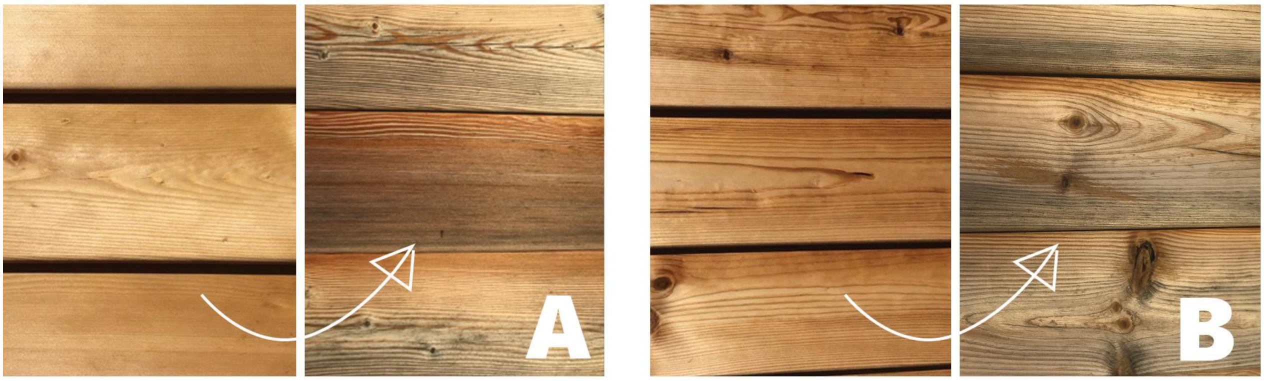


Figure 15: The appearance of wood constructions before and after 30 months of weathering: façade from Siberian larch untreated (A) and façade from thermally modified pine untreated (B)

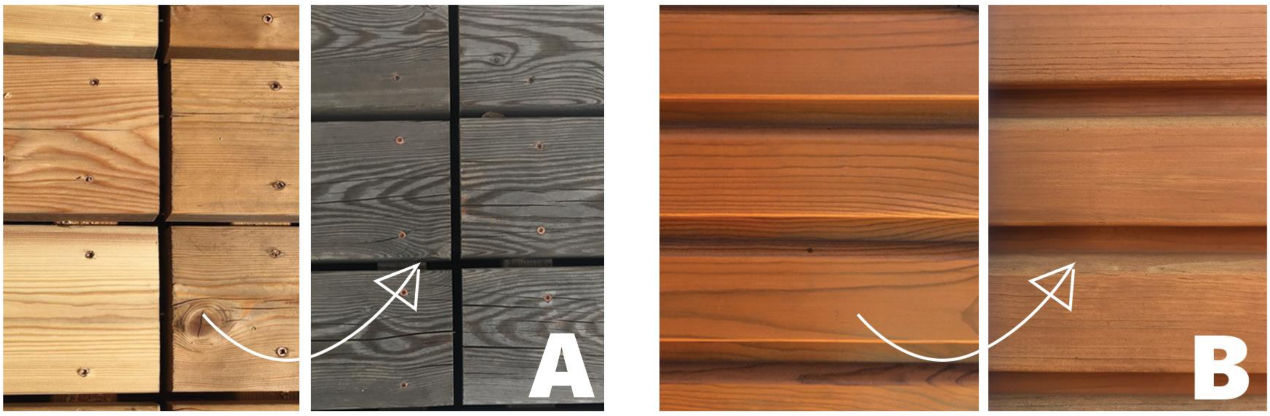


Figure 16: The appearance of wood constructions before and after 30 months of weathering: terrace from untreated Siberian larch (A) and façade from treated thermally modified pine (B)

3 CONCLUSIONS

To sum up the results from this 4-year experiment, the treated samples generally showed significantly more stable results than untreated ones in the first 12 months of weathering, as expected. In that period of weathering untreated samples distinguished by rapidly increasing colour and roughness changes. The untreated samples turned grey already after 4 months of weathering. After that, with increasing exposure period, the mould and more cracks appeared on their surface. But after one year of natural weathering, the coating started to degrade itself and more damages in the surface treatment (like flaking, peeling etc.) appeared. After 3 years of weathering, the coating was almost completely damaged, especially in the case of Siberian larch. Based on the overall results - measured values and visual evaluation - the better performance was observed for thermally modified pine, both in the case of treated and untreated samples. But in the case of untreated, there were no significant difference in comparison with Siberian larch.

The real built wood construction at HBH were characterized with unequal greying, roughening and cracking in the case of untreated wood. The treated constructions were noted for slight discolouration and loss of gloss. The decking was significantly more affected by weathering than wooden cladding covered by roof overhangs.

The pre-weathering of thermally modified pine did not improve the performance of surface treatment during weathering.

Combination of evaluating methods created a satisfactory idea of quality and durability of the tested wood samples along with a good assumption of their service life during natural weathering. Microscopic analyses of the coating clearly detected their degradation during exposure. Still, visual evaluation remains one of the most reliable methods of evaluation of surface degradation.

In conclusion, currently the trend of using treated or even untreated wood elements in the exterior is becoming more progressive. But wood is a natural material and it behaves accordingly. Basically we have two options - we can either accept the fact that untreated wood eventually turns grey (in the most cases unequally) and gets typical plastic structure, or we can apply suitable surface treatment which will prevent the wood from greying and roughening, but which has to be renewed after several years.