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PROTECTION THROUGH CONSTRUCTION OF A WOODEN MONUMENT IN RADOMLJE (SLOVENIA)

Biodegradation of the wood, photo-degradation of the coatings and major cracks appeared on a six-metre high oak monument built in 1960. Due to three displacements and exposure to increased moisture and pests, the monument lost its original appearance. Damage due to the fixation elements became so extensive that they threatened its load-bearing capacity. During the renovation work, the monument was subjected to original and specific constructional measures and its original appearance was restored. Restoration of the original details allowed water to flow off the monument easily, hence the wood could dry quickly. The weakened and worn parts of the wood were replaced or consolidated. Dilatation between the wood, metal and stone was stopped and further corrosion processes prevented. Restoration of the cracks prevented the entry and retention of water inside. Where this was not achievable, drainage was installed and aeration of the wood was enabled. By means of a central metal mandrel and a supporting system of adjustable bolts, the bearing capacity was improved and, in the event of possible displacements, centring of the monument was made possible. Removing the external fixation elements contributed to the monument's aesthetics. These innovative construction solutions may represent a model case for the future restoration of similar cultural monuments.

Keywords: wood decay, wood protection by construction, restoration, cultural property, consolidation

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Introduction

Wood used for outdoor applications is exposed to biotic and abiotic degradation factors, therefore it must be protected in order to achieve an adequate service life. It can be protected by measures of constructional, chemical and surface protection, whereby chemical protection is used as little as possible, only where necessary [Pohleven, Petrič 1992; Humar 2004].

Due to the shrinkage of wood when it releases moisture and its expansion when it accumulates moisture, wood is dimensionally unstable, which is one of its drawbacks [Torelli, Čufar 1983]. Project mistakes can also be the cause of building decay [Jokilehto 1986]. A great deal of damage to wooden constructions also occurs due to negligence and mistakes in renovation [Gockel 1996; Deu 2004]. In addition, atmospheric pollution in urban industrial environments accelerates harmful biochemical processes in wood [Herrera et al. 2004].

Wood with a moisture content below 20% is safe from infestation by fungi and most wood insects. Air-dry wood with a moisture content from 12 to 15% is safe from the majority of wood pests. The best protection for wood is to maintain conditions in which the wood is air-dry, which is possible with proper construction [Pohleven 1994]. To prevent biodegradation, the wood moisture content must be balanced with the air humidity where the wood is used. Monitoring air and wood humidity is necessary for the prompt maintenance of suitable conditions and the planning of protective measures [Gobakken et al. 2008; Finch et al. 2013]. Protective measures must be carried out correctly and in such a way that they can be monitored and repeated [Schmidt 2006]. The optimal approach is to use constructional solutions which ensure the durability and longer life of the construction. The best prevention is a carefully designed project which consequently includes elements of protection by design [Willeitner, Peek 1994; Brischke et al. 2010; Morris 2013].

Experts in the field of the protection of historical buildings and monuments incorporate the preparation of a conservation plan in protective measures, which includes constructional protection. This conservation plan attempts to implement the planned protective measures without the devaluation or loss of the original features [Kerr 2013]. Russell [2002] therefore stipulates, before the implementation of protective measures, prior identification and analysis of any defects and the causes of any damage found.

Nowadays, when much of the knowledge of our ancestors has been forgotten, standards established in this field are taken into consideration, in terms of the choice of wood species depending on wood durability [Pohleven 2012]. For example, wood for sleepers and bearers must have a natural or required durability allowing its use in hazard class 4 as defined in EN 335-1:2006. According to EN 350-2:1994, solid wood to be used in hazard class 4 must conform to natural durability class 1–2. Wood with natural durability of classes 3, 4, or 5 or containing non-durable sound sapwood must be treated to achieve the required durability.

Coatings play an important role in wood protection, while adhesive agents contribute to wood stability. The former protect wood from abiotic factors and highlight its decorative qualities, while the latter are part of the static support system. When construction joints are well performed, they do not cause deformations but enable constructional protection. Wallner [2004] states that in clamping a wooden pillar, rotations and movements must be reliably prevented so that bending moments are fully transferred to the supporting elements. However, loosening of the joint, stress cracking and instability of the construction often occur due to moisture at the site of clamping. Wood can also be damaged by corrosion, which can be caused by preservatives containing metal ions [Zelinka 2013]. Since wood with a moisture content of less than 10% is not subject to significant change when in contact with metal [Unger et al. 2001], it is advisable to prevent moisture affecting joining elements and to use rust-resistant joining elements [Piazza et al. 2005].

A good protective coating basically protects the wood against extreme oscillations of humidity, has good adhesion and elasticity, and adapts to the processes in the wood. Vapour-permeable coatings allow the diffusion of water vapour and, in addition, protection against UV rays prevents pest infestation. With their penetration into the wood, polymers certainly prevent the capillary rise of water in the wood but do not contribute to the diffusion of water vapour or the regulation of the moisture balance in the wood [Jirovš-Rajković, Turkulin 2002].

It has been found that darker pigmented coatings and coatings which do not have a water-soluble base better protect wood from UV rays and better prevent wood humidity oscillations than transparent coatings. Coatings that penetrate into the wood protect it against moisture less efficiently than coatings that make a film on the surface of the wood. [Hrastnik, Tišler 2006]. On the other hand, an incorrectly applied surface coating can accelerate the infection of wood with fungi. Despot and Glavaš [1999] found major infections of fungi in samples treated with alkyd coating, which were believed to be due to the poor vapour permeability of the translucent coatings.

In the renovation work presented in this paper, constructional protection stopped or at least slowed down further degradation of the monument, improved the conservation conditions and restored its original appearance. In order to achieve the aims of the project, innovative solutions for the constructional protection and stabilisation of the monument had to be developed, which could act as a model for the arrangement of similar cultural objects in the open air.

Materials and methods

Material

The monument of solid oak wood (Q*uercus* sp.) has an octagonal ground plan and is situated in the World War II cemetery in Radomlje. The monument was made in 1960. In 1981, when the cemetery was rearranged, the monument base, made from masonry units, was replaced with a concrete base and later, in 2006, with a granite pedestal. The monument is 600 cm tall, with a bottom diameter of 60 cm and is set on a granite pedestal 100 × 100 × 60 cm. The monument is protected at the top by a copper cover. The monument is decorated with a surface coating of angled rhombi painted in gold bronze. The monument is secured to a stone base using an iron ring with vertical slats bolted in place using bolts measuring 13 × 1 cm.

The following materials were used in the renovation:

- Oak wood (oak prisms and wedges, dowels with a diameter of 1 cm, oak bushings with a diameter of 5 cm, height 15 cm of Slovenian origin, from the Švelc sawmill, Kranj.
- Inox tube with a diameter of 7.5/4 cm, type AISI 304L, M20 inox bolts and inserts (bushings) with a diameter of 3 cm, height 10.5 cm, with an internal thread of 10 cm in height, from the Spanish manufacturer TTI – Tubacex tubos inoxidables, Llodio (Alava).
- Silvanolin – a biocidal product for wood protection from the Slovenian manufacturer Silvaprodukt, Ljubljana, Slovenia.
- Epoxy resin for the injection of Kemapox Fill 1000 (A/B component) with an additive for increasing thixotropy (microsilica), Kemapox Dens SM, from the Slovenian manufacturer Kema Puconci.
- Araldite 427 (epoxide) from the Swiss manufacturer CIBA-BASF Schweiz AG.
- 1 cm alkali resistant (AR) glass fibres from the French multinational corporation Saint-Gobain Vetrotex.
- Wood flour from the Slovenian company Samson Kamnik.
- Glass roving fabric RT500, 0.065 cm thick, from the Croatian manufacturer Kelteks, Karlovac.
- Paraloid B-72 granulate from the US manufacturer Rohm and Haas, a 15% solution of Paraloid B-72 ethyl acetate (from the Slovenian manufacturer, Samson Kamnik).
- Vivat oxide black pigment in powder form, bronze in powder form – Sirius Pigment Pearl – Zlati antik, from the Slovenian manufacturer Samson Kamnik.

- Urethane glue (PU) – two-component polyurethane foam, 2K Schaum, from the Austrian manufacturer Pichler Chemie GmbH, Ehrenhausen.
- Novilon – polyamide plastic produced by Akripol, Trebnje, Slovenia.
- Plastic (PVC) protective mesh produced by Weber Saint-Gobain, Grosuplje, Slovenia.

Methods

Interventions on the monument were divided into the following procedures:

1. Documentation and recording of damage on monument
   The cultural and artistic significance of the monument was established using the historical method. Sources and project documentation were examined and the causal-consequential relationship between the previous stabilization methods and damage to the monument were established using analytical and comparative methods. The previous method of fastening had led to comparable damage to the monument. In the phase of recording, the following were carried out: a visual inspection, documentation, register of damage and basic measurements of the monument.

2. Realization of constructional and chemical protection
   Constructional protection was carried out promptly and consistently at points where there was an inflow of water and wherever wood decay would occur due to moisture. The rotten parts in the zones of the previous fixation elements, as well as the weak points, were impregnated with Silvanolin.

3. Anticorrosion and surface protection of the monument
   Removing the old fastening system, coating the cleaned metal parts, the use of rustproof load-bearing and protective materials, and dilatation between materials prevented further corrosion processes. The monument`s aesthetic appearance was restored using surface colour coatings.

4. Static verification of the installation of the monument
   The innovative concept of the installation of the monument was based on deepening the monument boring, static calculation of the system of load-bearing bolts and a lengthened supporting mandrel, lifting, and dilatation of the monument from the stone base. In calculating the static model, D30 oak wood and S 235 structural steel were considered. The static calculation was made according to the standard Eurocode 5 [EN 1995-1-1: 2004].

5. Setting of the monument
   A specific base with bolts, which can be set and regulated, ensuring a firm support, and enable the centring and monitoring of the position of the monument, was developed and constructed.

Results and discussion

Analysis of damage

Once the monument was taken down, it was examined in detail and the damage to it documented. The monument was protected by a copper cover, which had caused galvanic corrosion where the metal came in contact with the wood. Flaking, dislodged wooden inserts and rotten wood were documented over the entire surface coating. The multi-layered decorative coatings were cracked and photo-degraded (fig. 1). Cracks, wooden inserts and rotten parts were visible where water had flowed into the wood. The greatest damage was found in the lower part of the monument, in the area of screwing, where radial cracks extended to the bore (fig. 2).

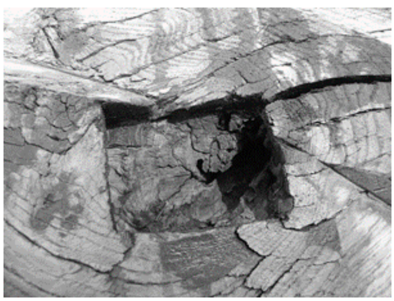

Fig. 1. Detail of photo-degraded surface and rotten area

Fig. 2. Damage to monument due to the fastening system

A 10 cm bore in the wood was only 50 cm deep and was badly cracked. The monument was mounted on a metal tube with 9 cm diameter and a height of 50 cm, which was fixed in a granite pedestal and filled with cement mass. The slats were enclosed within a metal ring which did not allow water to run off, therefore it accumulated, saturated the bottom of the monument and caused intense rotting.

At the points where the ring was screwed in place, pronounced tearing of the wood fibres and, to a height of 200 cm, radial and longitudinal cracks of up to 10 cm deep in the direction of the wood fibres were found. Brown rot and white rot, slightly higher above the screws, were found. On account of this, the lower section of the monument was severely damaged.

Due to the inadequate fastening, as well as biotic and abiotic factors, the monument was in an extremely bad condition. The short mandrel and loose screwing points could no longer ensure the bearing capacity of the monument. A new, innovative installation and integrated remediation of the monument was therefore planned.

Constructional and chemical protection

The copper cover, corroded bearing ring and bolts were removed from the top of the monument. After cleaning, aeration between the ring and wood and between the ring and the copper cover was assured using spacers, and the openings were protected against insects with a plastic mesh.

The fillings and colour coatings were removed from the surface of the monument. The surface, particularly the fillings, were sanded and levelled to the desired form. The wood humidity was 16%. The wood was chemically protected with Silvanolin, in such a way that the rotten parts, cracks and fillings were repeatedly permeated by dowsing, spraying and coating. The wood was then dried for one week. After drying, the wood humidity was 19%.

The filling places (deepening, niches) and wooden inserts were cut in the direction of the water outflow and reinforced with dowels and urethane glue (fig. 3). The rotten parts were filled with epoxy binder with added wood flour and AR glass fibres. The rotten parts not suitable for the insertion of wooden implants were thoroughly cleaned and strengthened with dowels and Paraloid B-72. In the open parts of the damage, unbound dry wood flour was scattered and the remaining volume was filled with Araldite. When the epoxy mass hardened, the residue of unbound wood flour was blown out through a water drainage duct, drilled at the lowest point of damage. The opening was covered with stainless steel wire wool, allowing drainage and aeration but, at the same time, preventing access for insects (fig. 4).

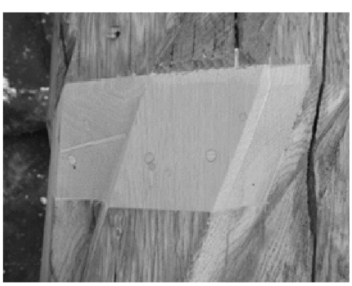

Fig. 3. Insert of new oak wood

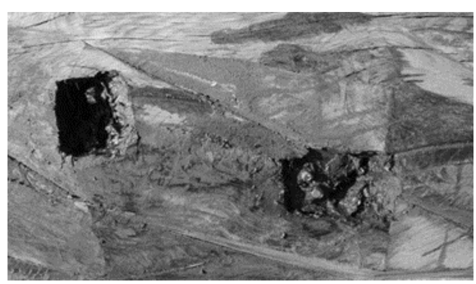

Fig. 4. Reinforcement of rotten parts with dowels and epoxy mass

The rotten wood at the site of the previous bolting was removed with a joiner's chisel, the areas were impregnated with Silvanolin and substitutive glued oak prisms measuring 35 × 10 × 10 cm were inserted. The peripheral part of the monument was structurally remediated so that, with the new concept of installation, it could bear the static load. The wood was drilled around the perimeter at a width of 10 cm and to a depth of 40 cm. It was then impregnated with Silvanolin and oak dowels were inserted using urethane adhesive (fig. 5).

The weakened zone of major radial cracks was fastened together with four butterfly wedges of glued oak wood and additionally secured against extraction. The cracks were cleaned beforehand, cleared by blowing and then impregnated with Silvanolin. In order to prevent the accumulation and retention of water above the wedges, drainage of the main cracks was provided through the wedges. The wedges were glued with urethane glue only at the sides and, on the edge above, the upper surface of the wedges was hollowed out into a funnel-like shape towards the centre, where a hole of 0.8 cm in diameter was drilled and covered with a mesh against insects. At a distance of 1.5 cm from the perimeter, a drip chamfer was also carved on the lower surface of the monument (fig. 6).

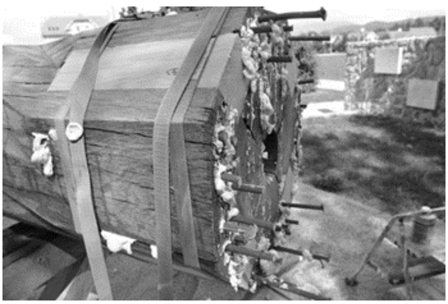

Fig. 5. Reinforcement of lower part of monument with oak dowels and prisms inserted with urethane adhesive

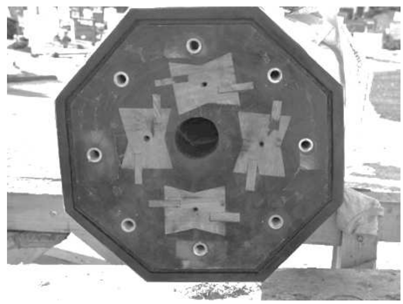

Fig. 6. Arrangement to stainless steel inserts with an internal thread. Drainage of main cracks through wedges

Water retention was prevented and, at the same time, aeration of the major cracks was enabled by providing drainage above the lower remediated part of the monument. Oblique ducts with a 0.8 cm diameter were added on four sides of the monument. The exposed portions of the ducts were deepened, cut in the lower section in the direction of the water outflow, and covered with mesh.

The constructional solutions applied functionally should protect the wood against moisture and should allow water drainage and aeration of the critical points.

This was followed by surface treatment of the monument. 7% diluted Paraloid B-72 was applied on the cleaned surfaces of the monument thus strengthening the monument, and a bonding layer for subsequent coatings prepared. The sunken parts of the surface were coated several times with 15% diluted Paraloid B-72 with added inorganic pigments and bronze powder. Other surfaces were coated with Paraloid B-72 with added brown and black UV-stable pigment in powder form. The monument's distinctive decorative appearance was thus restored.

Installation of the monument

An innovative installation system was developed. By increasing the depth of the boring of the monument by 50 cm to 130 cm, incorporating a longer supporting mandrel (tube) and supports with threaded bolts, the monument was raised from the pedestal by 5 cm, which enabled drainage, aeration, cleaning, centring and monitoring of the basic, most burdened part of the monument

During preparation of the pedestal for installation of the new mandrel (tube), previous elements of the external fixation, which spoiled the aesthetic appearance of the monument, were eliminated. In order to prevent destruction of the pedestal, part of the old tube in the granite pedestal was retained, the concrete filler and rust were removed from it and the tube was corrosion protected. A new stainless tube with a diameter of 7.5/4 cm was inserted into the old tube, centred, and the gap between the tube and pedestal was filled with the two component, highly adhesive, low viscous epoxy resin Kemapox Fill 1000. For drainage and aeration of both the tube and the boring, a 0.8 cm hole was drilled in the tube just above the pedestal and a spacer was welded onto the upper edge of the tube. A mesh against insects was placed in the upper part of the tube and in the small hole.

Dilatation of the areas of contact between the metal and the pedestal was performed to prevent corrosion processes. Novilon rubber caps, 4 cm in diameter and 0.8 cm thick, were placed on the adjustable bolts. The cap was held with the deeper part in the correct position, thus preventing direct contact between the bolts and granite and, at the same time, acting as a vibration absorber.

In case of dimensional instability and of smaller movements, the load was distributed evenly among the circumferential bearing bolts, helping to easing the tensions in the wood. The bearing tube was fixed at the base but not in the upper section, to allow the wood to react to external impact (fig. 7).

Fig. 7. New inox tube fixed at the base

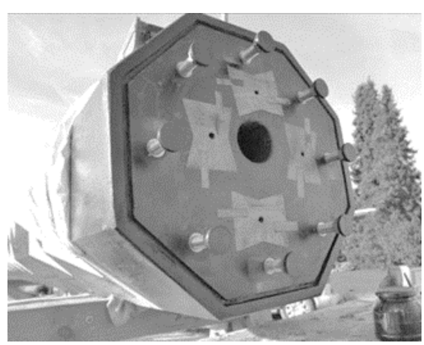

Fig. 8. Adjustable supporting elements of the monument

Since the new tube, with a height of 195 cm (135 cm above the pedestal and 60 cm in the pedestal) was sufficient to bear 60% of the load, eight M20 bolts were inserted on the periphery of the monument, to bear the remaining 40% of the load. They were bolted into stainless steel inserts with an internal thread. Each insert had a diameter of 3 cm and height of 10.5 cm, with a thread depth of 10 cm. The inserts with bolts were installed in a radius of 20 cm, 4 in replacement oak prisms in the original mounting points, and 4 in special oak bushings with a diameter of 5 cm and a height of 15 cm (fig. 8).

The bearing strength of the monument was checked by the static calculation of the system of load bearing bolts and the lengthened supporting mandrel attached to the stone base.

Monitoring the monument

After installing the obelisk on the pedestal, the bolts were set and tightened in such a way that the obelisk was supported by all the peripheral bolts and carefully centred. Due to the expected dimensional instability of the wood and the effect of the wind, occasional monitoring of the settings of the bolts and the state of the dilatation caps, meshes and top cover, as well as the condition of coatings, was envisaged.

Monitoring the condition of the monument in future is important for the timely planning of necessary interventions, however monitoring public monuments is very difficult, because the monuments are on different locations, not equipped with infrastructure and there is a lack of personnel.

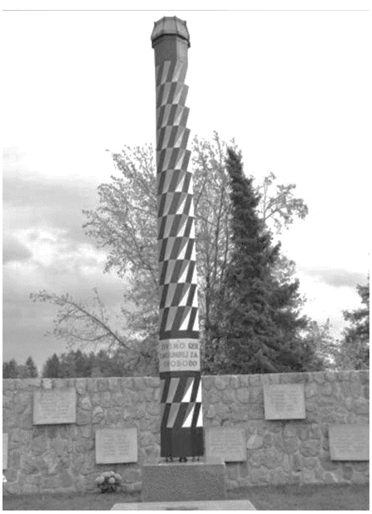

Fig. 9. Monument after restoration

Nevertheless, occasional monitoring of the fastening system, surface coatings, drainage holes and other parts of monument is envisaged, which will show whether the restoration of the monument has implemented preventive constructional measures to a sufficient extent or these should be upgraded during further maintenance interventions.

Measurement of the moisture content of the monument several times a year is also envisaged.

The innovative and statically-verified load-bearing system applied helps shape the architectural appearance of the monument and, at the same time, enables protection through construction (fig. 9).

Maintenance and possible problems in the future

Since the monument is erected in the open air, it is difficult to predict how unforeseen weather conditions will affect the obelisk in the future.

Due to the natural resistance of oak wood according to EN 350-2 [1994] and the constructional measures applied, it is possible to argue that, under normal climatic conditions and constant load, its service life is guaranteed for a long time. Due to exposure to the weather and dimensional instability processes in the wood, changes in the decoration and small cracks can be expected over time but these are manageable with regular annual maintenance and the renewal of vapour permeable surface coatings.

The renovation raises the question of a possible repetition of the restoration procedures and the reversibility of the materials, as advocated by Schmidt [2006]. Materials with tested properties were certainly added to the wood but their influence on the processes in the wood, and how they respond over the long term to changes in humidity and temperature in this specific case is not known. During possible repeat renovation, the question will arise of whether this particular solution should be changed or even removed. It is thought that this is unlikely as the renovation was carried out with great care. If the wood needs to be replaced in future due to heavy wear, the new solution allows the fastening system to be kept and enable the installation of monument in the same manner without damage to the system.

The procedures of constructional protection applied are technically repeatable, however it is considered that maintenance interventions should be adapted to the state of the obelisk and that new materials and procedures should perhaps be used. In the event of damage, some of the solutions are repeatable and maintenance work such as cleaning the cover and meshes, clearing the drainage channels by blowing, the installation of new meshes, the replacement of bolts and washers and the renewal of coatings do not require disassembly of the monument.

Another dilemma concerns the regularity of the application and knowledge of the materials used [Russell 2002]. During the restoration, much was learned about the monument and this was documented, as suggested by Morris [2013]. All the planned measures of constructional and chemical protection were carried out, although the effects will have to be monitored occasionally.

The innovative solutions developed will contribute to better preservation of similar cultural and historical monuments, therefore the study is essential for the development of restoration in general.

Conclusions

Due to incorrect fastening, the six-metre tall wooden monument in Radomlje was at risk of collapse. Incorrect interventions in the past had spoiled its appearance and it had been exposed to moisture. It is believed that the possibility of further degradation has been reduced by providing the monument with improved protection against the harmful conditions to which it will be exposed in the future.

The innovative and statically-verified load-bearing system applied helps shape the architectural appearance of the monument and, at the same time, enables protection though construction.

Technical measures, such as covering, cutting wood in the direction of rainfall, drainage, aeration, raising the monument from the ground at the pedestal, preventing prolonged retention of water in the timber and permitting rapid water drainage and drying of wood surfaces, are so important to obtain the monument durability.

In the process of the restoration of the monument, deficiencies were eliminated and the installation used should ensure the stability and service life of the monument, while allowing regular monitoring and regulation of the situation and simple maintenance work. The daring construction solutions have restored the original architectural appearance of the monument and thereby helped maintain its cultural-historical mission.

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