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Underground timber constructions from the First World War are well preserved after 100 years

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Underground timber constructions from the First World War are well preserved after 100 years

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ABSTRACT

During the Great War or World War I many underground constructions have been built for protection from shelling. They were an important part of the trench warfare as they were used as an area to rest and carry out other activities such as eating. They would usually range in size from smaller constructions that could hold several men to larger entities that could hold thousands of soldiers. In the context of tunnel warfare the construction of underground facilities was very extensive. About 180 dugout sites have been located in the Ypres Salient and since the 1990s some of them were entered (Doyle et al. 2002, 2005).
During use these dugouts which are typically timber based tunnels were kept dry, however got fully submerged when no longer in use. These wooden constructions remained under groundwater level and are very well preserved after approximately 100 years. Several of these constructions have been documented and one specific one is very much highlighted in 2017. As the 'Zonnebeke Church Dugout' is intended to open up for the public for some months and this construction was checked on different parameters. Wood species identification confirmed the considerable presence of wood from overseas origin, here Jack pine (*Pinus banksiana*). Although several low durability wood species have been used the decay rate found on the material is minimal and structural integrity analysis allows to ensure safe passage for visitors to the dugout.

Keywords: First World War, wood anatomy, structural integrity, waterlogged wood

1. INTRODUCTION

The Memorial Museum Passchendaele 1917 and the municipality of Zonnebeke drained the 'Zonnebeke Church Dugout' recently on September 26th 2016. The draining was part of large-scale scientific research on the possibility to temporarily open this unique underground site for the general public in 2017. The research was done in collaboration with the Flanders Heritage Agency and Archeo7. Because of his expertise in the field of underground structures, also amateur archaeologist Johan Vandewalle took part in this research. On October 1st, Minister-

President of Flanders Geert Bourgeois and the 1,000,000th visitor got a guided tour of this authentic dugout.

The draining of the deep-dugout provided the opportunity to survey the wooden timber structure and to accurately record its dimensions. The latter was intended to serve as a basis for the assessment of the structural integrity of this underground construction. Furthermore, samples were taken from the timber in order to document the spectrum of wood species used during the construction. These samples were also used for an inspection of wood degradation processes affecting these 100 year old timbers.

2. THE HISTORY AND DISCOVERY OF THE ZONNEBEKE CHURCH DUGOUT

In 1989, archaeological excavations were carried out in Zonnebeke in order to further document the remains of the local Augustinus abbey of which written sources attest its foundation back to 1072 AD. The main focus of this specific archaeological campaign were the remains of the local church that was completely demolished by warfare during the First World War. Within the foundation walls of this former church, a wooden construction was discovered. Soon archaeologists realized this construction was an undocumented deep dugout that was constructed to provide habitation and shelter against hostile fire during the First World War. In July 1989 the dugout was drained and documented for the first time in 100 years (Figure 1).

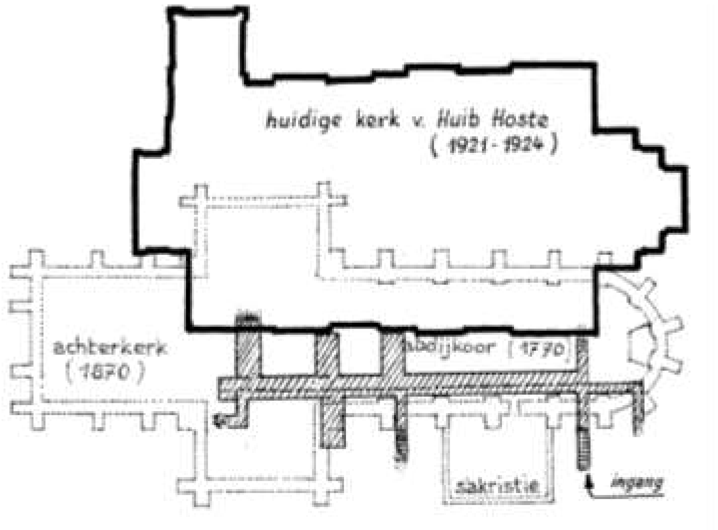

Figure 1: Position of the 'Zonnebeke Church Dugout' to the church in Zonnebeke with reference to current and past position of church.

At the moment of its discovery, its origin, time of construction and engineering conditions were unknown. Historical and archaeological research revealed that this dugout was occupied only by allied forces, as no material traces or written reports of German military were found (Deseyne 1990). Zonnebeke was occupied by German forces from May 1915 onwards. On September 26th 1917 Australian troops finally succeeded recapturing this strategically important village during the Battle of Passchendaele (Third Battle of Ypres). During this battle, the allied troops realized that only few aboveground shelters were still available on the battlefield, as the surroundings were completely transformed into a crater-ridden and treeless landscape. This induced the strategic need for underground constructions that could withstand incoming enemy fire. In Zonnebeke, the Canadian Tunneling Company tried to gain access to the crypt of the former church and to use this room for shelter and habitation. However, despite multiple efforts the crypt was never found.

Few weeks after the conquest of Zonnebeke, the Canadian troops were replaced by the 1st Australian Tunneling Company. Section 4 of this unit starts digging a shaft on the southeast side of the former church on January 1918. From March 1918 onwards, the British 171 Tunnelers Company maintain the dugouts in and near Zonnebeke. After a final and successful counter-attack by the German troops in April, Zonnebeke again becomes occupied territory until its liberation end of September 1918.

The Zonnebeke Church Dugout could be accessed by two separate stairways, which lead to the central hall which is *ca.* 30m long and 2m high and is situated 5m below the current surface level. Four rooms were equipped with racks that were used as bedding for the military. Furthermore, at the extremities of the dugout, three unfinished or filled tunnels were found. The framework of the dugout consists of wooden beams with a rectangular section. The beams of the ceiling rest on two upright wall beams (Fig. 1). To prevent the walls from collapsing, blocks were nailed in the upper and lower corners. Today, nearly all of these blocks have come off due to the severe corrosion of the metal nails. In the centre, a steel I-frame supports the ceiling beams.

3. CONDITION ASSEMENT OF THE CONSTRUCTION TIMBERS

The timbers used for the construction of this dugout have been preserved due to the high water table in the clayey soil in Zonnebeke. All timbers have experienced waterlogged conditions over the last 100 years. During the reopening of the dugout September 2016, sections were sawn from large detached timbers and core samples were taken with an increment borer from the smaller posts and remains of the racks.

3.1 Wood species identification

From the 21 samples, thin sections were prepared for transmitted light microscopy. Wood anatomical features were recorded according to the IAWA list of microscopic features for hardwood/softwood identification (Wheeler *et al.* 1989; Richter *et al.* 2004). Taxonomic identification was performed using identification keys (Schweingruber 1990), illustrated atlases of microscopic thin sections (Schweingruber 1990, Wagenführ 2007) and online databases of wood anatomical description (‘Inside Wood’, http://insidewood.lib.ncsu.edu/search [2010] and ‘Wood anatomy of Central European species’, www.woodanatomy.ch [2010]). Using this set of reference material, 17 out of 21 samples could easily be determined up to species or genus level (Table 1). All these species belong to the western European flora. Especially the hardwood species (oak, hornbeam and elm) probably reflect the use of local wood resources. Elm, for instance, was abundant in the local boccage-landscape in the southwest of Flanders at the beginning of the 20th century. Wood from elm trees were used for smaller posts and especially for the racks used for bedding. Scots pine is not native to the Flemish region, but was massively transported to the western front from plantations in France (Haneca 2006, MacLean 2004).

Table 1: Wood species identification of 21 samples from the Zonnebeke Church Dugout.

Species	Number of observations
Pinus sylvestris	4
Pinus banksiana	4
Ulmus sp.	9
Quercus sp.	2
Carpinus betulus	2

Four remaining samples display anatomical features that are similar to Scots pine (tracheids with dentate cell walls, resin canals, …), but also a few features that are not observed with *P. sylvestris* and uncommon in European conifers (occurrence of biseriate tracheid pitting, pinoid cross-field pitting with 3-5 pits per field, …) (Figure 2). The expertise and reference collections of the Laboratory of Wood Anatomy and Xylarium of the Africamuseum allowed to determine the exact wood species: *Pinus banksiana* (Jack pine), a North American pine. Its native range in Canada is east of the Rocky Mountains and the north-central and northeast of the United States. The historical context of this underground timber construction combined with the wood anatomical observations make it clear that for the wall and ceiling planks of the deep dugout, the Canadian and later Australian Tunneling Company relied on timber that was brought to the battlefield by trans-Atlantic transport.

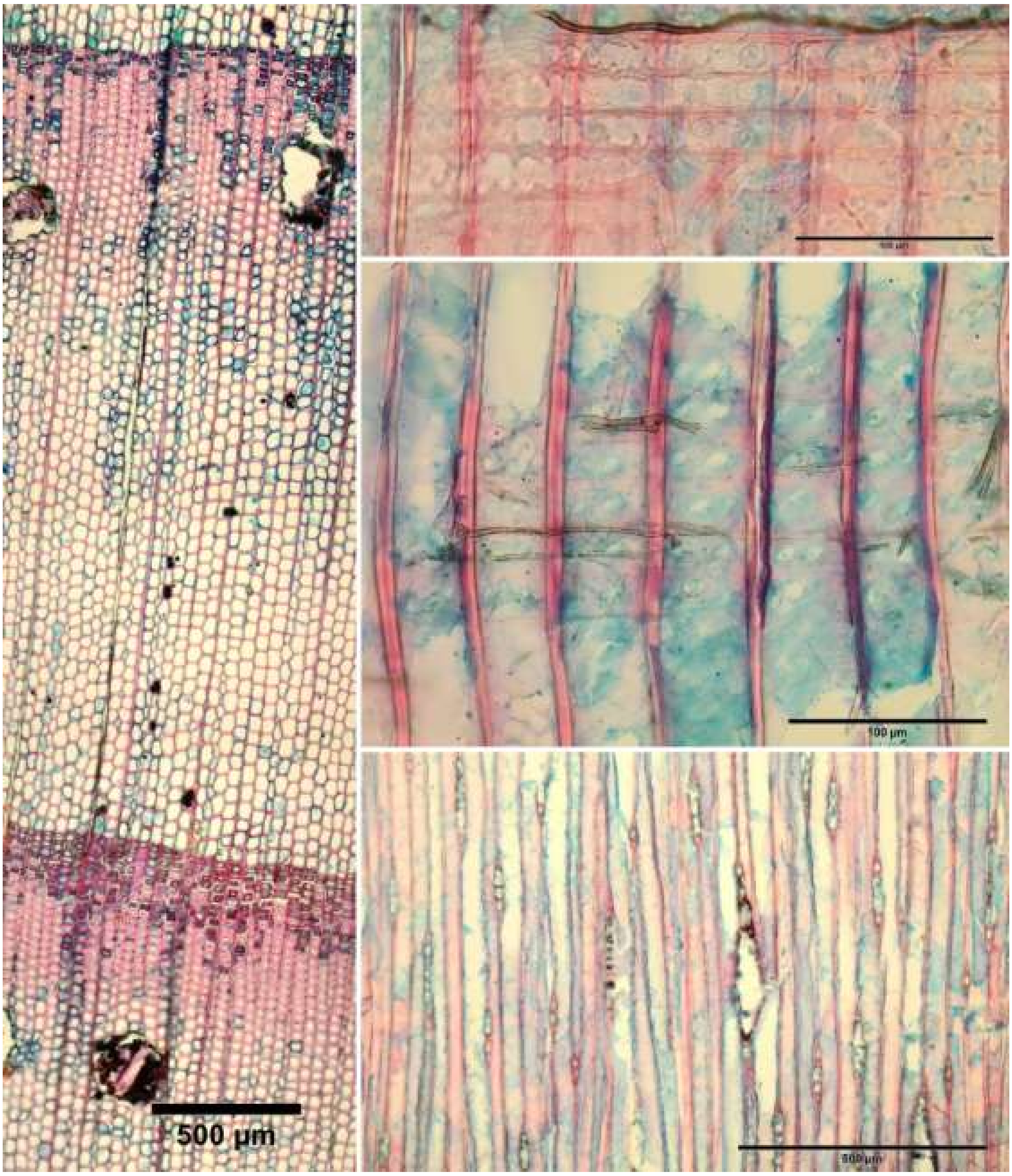

Figure 2: Thin sections of *Pinus banksiana* timbers from the Zonnebeke Church dugout. Transverse section with resin canals (left). Dentate inner cell walls of the ray tracheids (upper right). Pinoid pits in the cross fields (central), and ray of 3-1à cells high (lower right).

3.2 Supplying the tunnels in 1917

According to Barton and co-authors (2004) in 1917 in French forests alone the British Government was maintaining two RE Forestry Battalions comprising around 2200 men, plus fifty-six companies of the Canadian Forestry Corps, and 13000 unskilled labourer, mainly Chines Labour Corps, Indian troops and German prisoners of war. Ready sawn timber was also being imported from Britain, the Baltic, America and Canada. Between April 1917 and November 1918, over one million tonnes of sized timber was dispatched to the various armies at the front (Barton *et al*. 2004). The fact that several beams checked in the Zonnebeke Church Dugout are Jack pine (*Pinus banksiana*) originating mainly from eastern Canada underpins that timber was still being shipped across the Atlantic by 1917. By that time however, the main body of timber was brought to the battlefield from French forests as – due to the presence of German submarines in the North Sea – oversea navigation had become a risky operation (Bird & Davis 1919).

Most beams used at that time were 9 x 3 inch and put into position flat and put close to each other. Limited spacing allowed increasing potential to withstand snapping by clay pressure or even just limit excessive bowing of the timbers.

By July 1916 the British had standardised the interior dimensions of all their workings to just three sizes: (1) Ordinary galleries (offensive or defensive tunnels): 4’ 3” (130 cm) by 2‘ 3” (69 cm); (2) Galleries near the shaft bottom or for the first 75-100 meters: 5’ 0” (152 cm) by 2’ 6“ (76 cm); and (3) Galleries for communication of men: 6’ 0” (183 cm) by 3’ 0” (91 cm). As gallery dimensions were somewhat standardised the beams used are often similar in length. Top and bottom sill for dug-out passages and main sub-ways were respectively 2’ 9” (84 cm) and 3’ 6” (107 cm) or 4’ 0” 122 cm). The height (vertical timbering, side trees) was 6’ 4” (193 cm) up to 6’ 6” (198 cm) (Barton *et al.* 2004). Conversion used here: feet ‘- 1 ft = 30.48 cm and inches “ - 1 in = 25.4 mm.

Observations from the Zonnebeke Church Dugout confirm that thicknesses are sometimes only 2.5 “ (63-64 mm), however most are 3.0 “ (75-76 mm) corresponding with widths of 7.0 “ (175-180 mm) and 9.0 “ (225-230 mm) respectively and as such corresponding to common dimensions used in North-America. The length of top and bottom sill are similar the side trees in this dugout allowing a double passage, but also requiring a central support.

3.3 Decay

The timber used for dugouts during World War I have been submerged for approximately 100 years since major parts are below the groundwater level. Wood in waterlogged conditions is not degraded by basidiomycetes due to lack of oxygen. However in use during the war the timbers were subject to conditions closely related to those identified now as use class 4 according to EN 335, hence soft rot attack might have occurred then or probably also later when conditions might have been comparable at high moisture content but not fully waterlogged.
Similarly, wooden foundations under historical buildings has been reported as being primarily affected or threatened by bacterial degradation (Klaassen 2008). Bacterial decay is however a very slow process and affecting the overall mechanical performance of poles and beams to a limited extent. Klaassen (2008) explained soil characteristics as well as flow of water might play a role in the degree of degradation but over a period of approximately 100 years foundation poles showed only severe bacterial decay up to often not more than 20 mm from the circumference.

In Figure 3 the central tunnels of the Zonnebeke Church Dugout the wooden construction seems to be intact while most metal beams and connectors show major degradation. The groundwater was constantly at a high level over the past 100 years for most of the World War I underground constructions, though it remains unclear what part of the superficial degradation (Figure 4) is related to the in use period or whether it is related to the last 100 years. Analysis of the decay types present showed features of bacterial while presence of soft rot or even basidiomycetes decay was not found on the samples examined (Figure 5). Total disintegration of the cell wall was observed. Furthermore except for the compound middle lamella and some parts of the S3-layer all former cell layers were substituted by some amorphous residue material.

Figure 3: Central tunnel and adjacent room equipped with the remains of racks used as bedding for military in the Zonnebeke Church Dugout, 100 years after its construction by Canadian and Australian Tunneling Companies (photo K. Vandevorst - Flanders Heritage Agency)

Figure 4: Cross section of a beam extracted from the Zonnebeke Church Dugout, showing a limited zone of degradation.

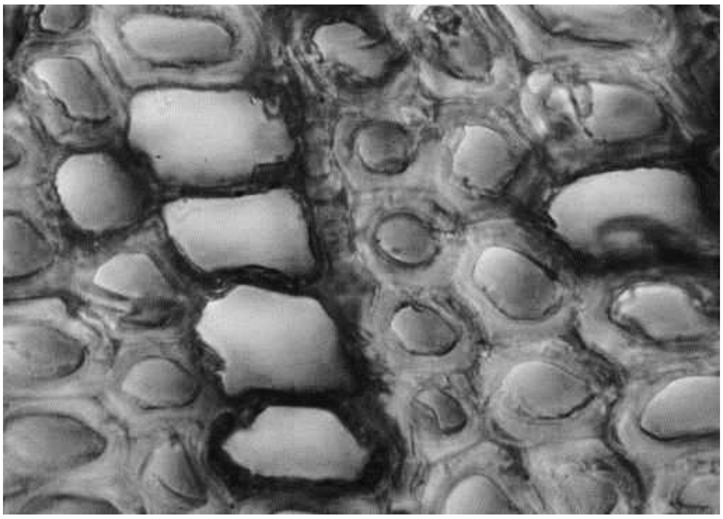

Figure 5: Micrograph cross section of the decayed zone of a beam extracted from the Zonnebeke Church Dugout showing features related to decay types.

4. STRUCTURAL INTEGRITY

To allow visitor access to the Zonnebeke dugout the construction was assessed on structural integrity. Figure 6 illustrates the structure of the central corridor of the dugout. This cross-section is based on the three-dimensional scan that has been performed during the inspection of the dugout in September 2016. The bearing capacity of the wooden structural elements of the dugout were calculated according to both the outdated Belgian wood standard (STS 31 1967) and the current European standard for the calculation of wooden structures (EN 1995-1-1 2004). As the beams in the ceiling and walls are loaded according to their weak axis, mainly the thickness of the beams determines their strength. The measured thickness of the wooden beams varies between 64 mm (2.5 ") to 76 mm (3"). For the calculations, the characteristics of respectively softwood (STS 31 1967) and class C22 timber (EN 1995-1-1 2004) are assumed.

The soil layer on top of the dugout ranges from 2.50 to 3.50 m. In the deepest part of the dugout, the ceiling bears the heaviest load, and therefore the calculation is carried out for both the deepest and the shallowest section. The walls of the dugout bear the horizontal earth pressure (active pressure).
The most important criterion is the restriction of the bending stress to an allowable value in order to avoid fracture. The current European standard imposes additional safety factors for timber, considering the duration of the load and the climate conditions of the timber. Both load duration (permanent earth pressure) and climate conditions (contact with ground water) are unfavourable for the strength of the wood and lead to additional restrictions of the allowable bending stress. The table below summarizes the results of the calculated bending stresses (unity check = ratio of the calculated stress / the admissible stress). The range of the unity check mentions the result of both the shallowest and deepest part of the dugout (Table 2).

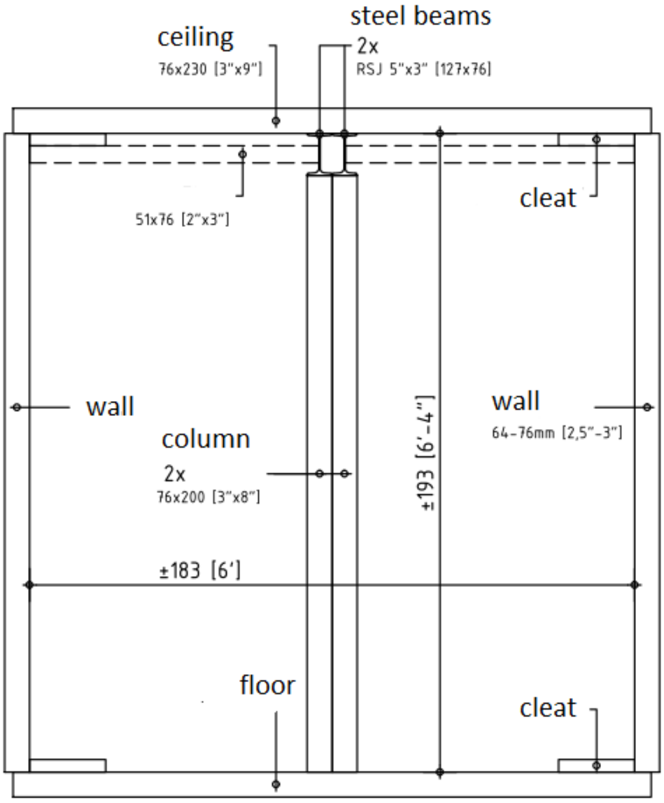

Figure 6: Structure of the central tunnel of the Zonnebeke Dugout (Ingenieursbureau Norbert Provoost bvba)

Table 2: Results on structural integrity calculation of the wood construction in the Zonnebeke Church dugout, assessment based on unity check bending moment

Component	Dimensions [mm]	Outdated Belgian STS 31 (1976)	EN 1995-1-1 (2005)
Ceiling beams	76 x 200	OK	OK
	64 x 200	OK	84-124 %
Wall beams	76 x 200	OK	83-123 %
	64 x 200	94-138 %	115-169 %

Although the unity check of the 64 x 200 mm wall elements seems alarming, the size of 64 mm is the absolute minimum that was measured. In reality, most of the elements are thicker than 64 mm. Moreover, the actual horizontal earth pressure on the wall elements will be less than the calculated theoretical earth pressure. The cohesion of the soil is very large as illustrated by the vertical talus in Figure 7. However, part of this cohesion is an apparent cohesion resulting from the under-pressure between the soil grains due to the partial water saturation of the soil. Due to saturation (rain water infiltration) or weathering of the soil (drying shrinkage) this apparent cohesion can decrease rapidly. The structural calculation of historical monuments according to current standards always has to be considered with the necessary differentiations. However, the calculation illustrates that the dugout is a carefully designed military structure that already holds for a 100 years.

Figure 7: Vertical soil between 2 wooden frames in an unfinished tunnel of the Zonnebeke Dugout (photo Ingenieursbureau Norbert Provoost bvba)

5. CONCLUSIONS

Wood from beams of the Zonnebeke Church Dugout that has been installed as tunnel construction material during World War I as part of the warfare Ypres Salient was investigated to check the potential of being used for visitors access for some months in 2017. This dugout dates back to 1917 and seems to be in good condition. Superficial decay mainly of bacterial origin underpins this and complementary analysis of structural integrity allowed deciding to open the dugout for the public. The identification of the wood species used confirmed that not only local species were used but that at that time considerable amounts of timber imported from North-America were installed. Although no specific preference for more durable species could be found, all loadbearing components seem to be still functional while connectors and metal structural components degraded considerably during 100 years in water and soil contact below the ground water level.

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