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# Characterization, performance and replacement stone compatibility of building stone in the 12th century tower of Dudzele (Belgium)

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ABSTRACT

For restoration and intervention on natural stones in historical buildings, it is important to pay attention to the origin and condition of the original building material. A prominent part of the façade of the 12th century tower ruin of Dudzele (Province of West-Flanders, Belgium) is constructed with buff-coloured limestone which survived almost nine centuries of environmental and anthropological stress. Microscopical research allowed one to identify this stone as Caen stone (France) which is an important historic building material in northern France and Britain. Additional petrophysical tests confirmed this identification. Based on the stone's petrophysical properties and an evaluation of its decay state, criteria for properties of a replacement stone in a similar material could be established.



## 1. Introduction

The ruins of the mediaeval tower of Dudzele (Province of West-Flanders, Belgium; Fig. 1) are the only remnants that nowadays testify of the former Romanesque pilgrimage church erected in stone from the 12th century onwards. Durable construction materials like stone allow one to investigate remains of nine centuries of history at this location. In fact, natural building stones are of great importance for the built heritage (ICOMOS, 1964; Přikryl and Török, 2010; Smith et al., 2010; Cassar et al., 2014). Their present-day value is considered crucial as they reflect the historical use of natural resources, historical trade ways and architectural development of a region. However, their present-day condition may largely differ from the original one as a result of stress factors acting on the stone over time (McCabe et al., 2010). For safety, functionality and both aesthetic and historical considerations it is important to conserve natural stone within historical buildings. In order to respect the building's authenticity and character, it is therefore necessary to decipher the stone's origin, its current condition and the environmental changes to which the stone was exposed over time. The onset of each respectful and durable restoration project thus typically requires a preliminary case–study of the material's identity and condition.

Currently, public access to the mediaeval tower ruins of Dudzele is prohibited because of hazardous falling debris. The new restoration project aims to restore the building's stability and functionality whilst preserving the original building material as appropriate as possible. Unfortunately, not all materials used were documented or archived. Therefore, our research aims are to determine the unknown origin and to assess the deterioration and performance of the stones and establish criteria for replacement stones. As most of the stones could be identified macroscopically as Fieldstone, Römer tuff, Lede stone and Luxembourg sandstone, special attention was paid to a buff-coloured limestone with a packstone texture composing the lower façade.

### 1.1. Historic environmental and anthropological significance

Dudzele is located in the polders, approximately 7 km from the Belgian North Sea coast. In the 12th century, the Zwin inlet extended more inland in the direction of Dudzele (Fig. 2). The Zwin's natural tidal channels and artificial waterways provided the area with excellent transport routes to which cities as Bruges (Belgium), Damme (Belgium) and Sluis (The Netherlands) owed their mediaeval wealth (Charlier, 2011). In the period between 1150 and 1161 A.D., the town of Dudzele started the construction of a major Romanesque church (Wintein, 1967). Later expansions with chapels reflect the maintenance and ongoing use of this religious building during the 14th and 16th centuries. However, from the second part of the 16th century onwards, socio-economical instabilities jeopardized and threatened its further development. A religiously inspired revolution associated with the Protestant iconoclasm of 1566 stripped multiple churches from their rich decoration and religious wealth. During the following Eighty Years' War, the church was looted and vandalized in 1583. It never regained its old glory and was only partially repaired using bricks instead of natural

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Fig. 1. Tower ruin in Dudzele as seen from the northwest. The lower façade is mainly built with buff-coloured limestone, the upper masonry with fieldstone and parts in brick.

stone. In addition to these anthropological threats, the climatic changes brought along by the Little Ice Age could have induced an additional environmental stress to the stone. In 1673 the crossing tower finally collapsed, probably as a result of environmental and anthropological stress combined with inadequate maintenance. It was then decided to construct a new church, partly on the older fundaments. In the beginning of the 18th century another part of the remains collapsed. Most of the original church has now fallen into ruins with the exception of the tower still present today. This remaining tower is the southern one of two, which were originally flanking the main westerly entrance (Figs. 1 & 3A). Above these a new bell tower was built in brick. Although poorly documented, this tower ruin was restored in the early 1900s and again in 1972. A new restoration is planned for 2016.

## 2. Methods

The natural building stones were identified based on macroscopic determination (with the naked eye). Stones which could not immediately be identified were sampled for further microscopic study. A historical background check was performed to list the main construction and destruction phases. A cartography of the lower façade limestone was made by visual observation (Fig. 3A & B). The buff-coloured limestone in this façade was subdivided in three categories based on the following criteria: volume intact (category A); visible deterioration with visible fissures or cracks, meteorological weathering and partial loss of volume (category B); strong retreat of surface with high loss of volume and sanding (category C).

A Zeiss Axioscope with Axiocam was used for optical microscopy on 30 μm thin sections. SEM–EDX was carried out on polished sections with a JEOL II SEM. X-ray diffraction (XRD) patterns were collected with a Philips X'PERT system and interpreted using X'PERT HighScore Software. High-resolution X-ray computed tomography (HRXCT) was performed at the Centre for X-ray Tomography at Ghent University (UGCT; www.ugct.ugent.be) using a custom-built set-up (Masschaele et al., 2007). The X-ray tube was operated at a power of 9 W and a voltage of 100 keV. The sample diameter was 2 mm and the obtained voxel resolution is 3.69 μm. Octopus software (Vlassenbroeck et al., 2007) was used for reconstructing the images and Morpho+ software for 3D image analysis (Brabant et al., 2011).

Physical properties were determined in the lab after cutting the samples to cubes of 50 × 50 × 50 mm. Open porosity ($p_o$) and apparent

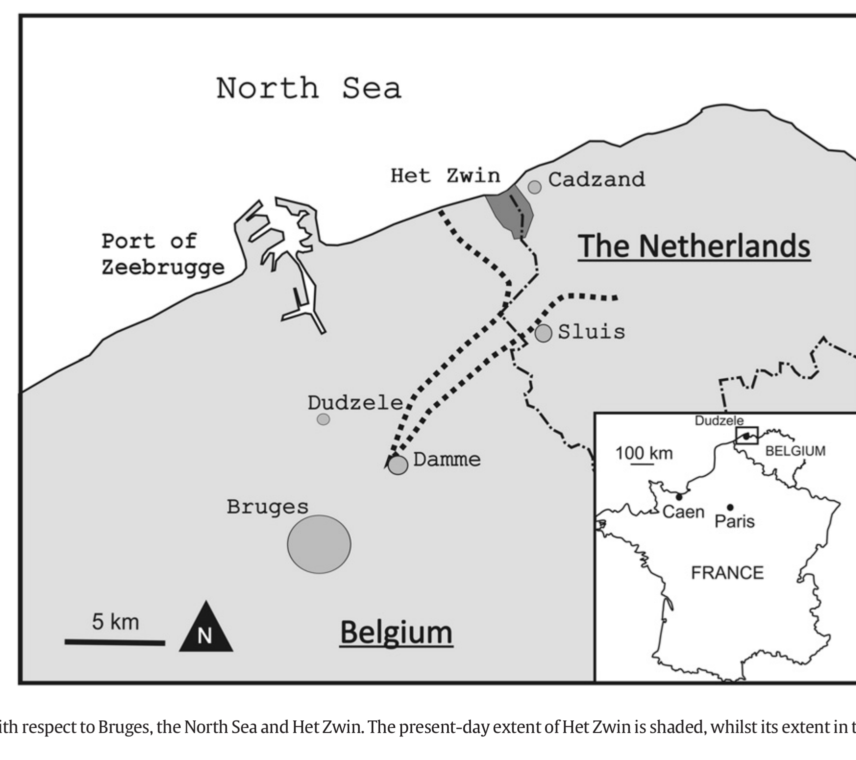


Fig. 2. Location map of Dudzele with respect to Bruges, the North Sea and Het Zwin. The present-day extent of Het Zwin is shaded, whilst its extent in the 12th century is represented by the dashed line.
Adapted from Wintein, 1967.