Monitoring moisture regimes and deterioration of historic limestone walls in Oxford

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Overview of sites and methods

Rapid, catastrophic decay is observable on a wide range of walls within the historic centre of Oxford. Both old and new oolitic limestone walls in a number of different contexts (e.g. roadside or not, restored or not) suffer from deterioration. For this project, a number of walls were chosen to reflect a range of dates, locations and types of walls, given the constraints of access and permission.

The locations of the walls studied are shown in the map below.

1. **Worcester College** – three sites studied, i.e. a) a suite of walls around the entrance door to the college, b) part of the roadside boundary wall and c) part of the older section of the college in the main quadrangle.
2. **Brasenose College** – part of the front wall of the main college building
3. **Magdalen College** – a section of the boundary wall along Longwall Street, which includes the outer wall of a small tower.
4. **New College** – two sections of the outer walls of the cloisters on New College Lane
5. **Sheldonian Theatre** – part of the so-called ‘Wren Wall’ which is part of the old boundary wall of the Sheldonian Theatre.
Each wall was surveyed following a standard protocol, to map both the nature of the wall and how it is deteriorating. Baseline surveys were also made of hardness (using an Equotip rebound device) and the stone types used. Monthly monitoring was carried out for over a year between September 2007 and December 2008 of surface moisture (using a Protimeter) and surface temperatures (using a 2D IR thermometer) of a sample of blocks (both those that were rapidly deteriorating and those that were not). Monthly sampling was also carried out over the same period of debris production by rapidly deteriorating patches of stonework. Two field campaigns were also carried out (in association with Queen’s University, Belfast) to monitor topographic change in the walls (using ground-based LIDAR and a laser-based object scanner) in 2006 and 2008. Finally, a number of vertical profiles were investigated in more detail to document both subsurface moisture regimes (using 2D resistivity surveys in September/October 2006 and July 2007) and surface moisture (using Protimeter in January 2009) at some of the sites.
Worcester College

a) Walls surrounding the entrance to the college

Four sections of the main wall of the front of Worcester College were studied as shown in the image below.

Age: The original stonework here dates from the 18th century when the ‘new’ buildings of the college were erected between 1720 and 1786. Restoration work was carried out in the early 1960s involving some stone replacement and cleaning.

Stone types: The 18th century stonework is Headington Stone, whilst the 1960s replacement blocks are Clipsham Stone.

Deterioration status: The stonework is generally sound, but slightly soiled from traffic and other pollution. There is evidence in some places of an old surface treatment, which might have been applied to help preserve the stonework and/or improve the colour. Some blocks show blistering patches, which often look stable. However, some blocks, especially towards the base of the ashlar exhibit intense hollowing which looks much more active.

Rapid hollowing at the base of ashlar at the south side of the entrance door
Graph showing variation in Protimeter readings (%Wood Moisture Equivalent) for a hollowed and sound block on the north-facing dining hall wall.
b) The roadside boundary wall

The roadside extent of the college buildings and grounds is delimited by a boundary wall, which ranges in date and style of construction. The front and back elevation of one part of this wall (marked by the red circle in the image below) was studied, the front looks to have been rebuilt in the early 20th century whilst the back is original.

Age: Uncertain, although parts of the boundary wall probably date from the 15th century

Stone types: Mixed stone (probably at least Headington, Weldon, Clipsham and Bath)

Deterioration status: Both the restored front side of the wall facing the road, and the original side facing the garden show patches of rapidly deteriorating stone, especially towards the base of the wall.

Inner part of Worcester College boundary wall, facing west
Outer, roadside part of the boundary wall, facing east
c) Buttery wall, main quadrangle

The south side of the main quadrangle (which faces north) is composed of a series of buildings dating back to the 15th century which have been remarkably little altered since then.

**Age:** Probably late 15th century

**Stone types:** Probably Wheatley Stone. The stone was washed in the early 1960s and possibly some repairs were then carried out to the windows using Weldon Stone.

**Deterioration status:** Much of the ancient stonework looks in good condition, with only superficial decay and light soiling.

Monthly Protimeter values (% Wood Moisture Equivalent) from a range of blocks under the windows of the buttery wall, September 2007 to December 2008. As one would expect the harder sill stones are drier throughout the period.
Sheldonian Theatre, Wren Wall

The Wren Wall dates from 1660 and is thought to be the only remaining external stonework from the original construction of the Sheldonian Theatre. The wall was built to provide a boundary wall around the theatre, and niches within it were constructed in order to display the Arundel marbles. Since construction, the wall appears to have been patchily restored and cleaned, mainly in the 19th century, but nothing has been done to it recently (although the University of Oxford is planning to restore it soon). The wall, which faces east and away from passing traffic, is now in a very bad condition, with lots of deteriorating and soiled areas.

Age: Late 17th century

Stone type: Originally Headington Stone, now patched with an array of stone (including one block of dark brown sandstone)

Deterioration status: Very badly decayed in places, with old soiling and some algal growth.

Two areas of the Wren Wall studied in detail
Decay mapping of part of the Wren Wall illustrates the distribution of different types of decay features. The most seriously damaged parts of the wall are found within the lower section, parts of which are also seen from both Protimeter and 2D resistivity surveys to be extremely wet.
Brasenose College

The walls making up the front of Brasenose College, facing east on to Radcliffe Square, have recently been restored (2004-5) using a combination of replacement of highly deteriorated stones, coupled with cleaning and dressing back of soiled and partly decayed blocks, and simple cleaning of intact blocks.

**Age:** 16th century

**Stone type:** Original stonework is Headington Stone, with some refacing in Weldon Stone in the early 1960s.

**Deterioration status:** The stonework now is clean and generally in good condition. The Headington Hard stone plinth is heavily pitted in places. The façade is away from traffic.

Area of stonework studied in detail  Pitted Headington Hard stone plinth
Magdalen College

The largely west-facing boundary wall of Magdalen College, which marks the edge of the gardens and runs alongside Longwall Street, was constructed from the 15th century onwards. After building, it appears to have been made higher at a later stage through the addition of a castellated top. The wall has experienced considerable deterioration, and has been patched and repaired at various times, notably in the late 1980s. Just following the start of this project the entire wall was cleaned and a limited amount of dressing back of heavily soiled and gypsum-encrusted surfaces undertaken. Within the boundary wall there is a small tower, seen in the left hand side of the image below.

Age: Late 15th century, with later additions and patchy replacement of stone.

Stone types: Probably Headington Stone with later blocks of other stones

Deterioration status: The wall shows much evidence of active deterioration, with some rapidly hollowed areas (particularly near the base of the wall). The wall was highly soiled until the recent cleaning, and is adjacent to a very busy road.

Protimeter wetness values from stones on tower, showing large periods of near saturation
New College

The cloisters of New College were built in the 14th century, and the road-facing side of the walls appear to have received very little restoration or cleaning since then. A section of the wall appears in W J Arkell’s 1947 book ‘Oxford stone’ illustrating that, apart from extensive soiling and development of gypsum crusts, the walls remained largely pristine at that time (as evidenced by the visible medieval tool marks). Today, many parts of the walls remain equally pristine, but there are also extensive patches of rapidly deteriorating stonework.

Cloister walls at New College on left side of the image

Age: Late 14\textsuperscript{th} century

Stone type: Headington Stone (with Headington Hard stone used for the plinth). No evidence for any repairs or restoration.

Deterioration status: Heavily soiled and gypsum-encrusted (presumably as a result of coal and oil smoke in the 19\textsuperscript{th} and early 20\textsuperscript{th} century). There is rapid cavernous weathering occurring in several places, especially just above the plinth. Other areas are showing rapid, but more superficial, removal of the black crusts across the whole profile. Whilst vehicles used the road in the 1960s, in recent years there has been virtually no traffic.

Two sections of the wall were studied in detail, one facing west and one facing south.
Part of the south facing section of the wall studied, showing the location of two of the 2D resistivity profiles monitored. As the Protimeter records below show, the black crusted stonework stays wetter than stonework with exfoliating crusts.

Monthly Protimeter readings (% Wood moisture equivalent) from profile with exfoliating crusts (pictured on the left).

Monthly Protimeter values from black crusted profile (block 2A on plinth, others on overlying stonework)