Introduction to stone in historic buildings: characterization and performance

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Interest in natural building stone, especially as used in historic buildings, is significant. This is demonstrated by the large number of publications that annually appear on stone, its properties, use, behaviour and treatment, and in the conferences on these subjects that are held in all parts of the world. In 2012 and 2013, the *12th International Congress on the Deterioration and Conservation of Stone* (New York, USA), *CRYSPOM III – Crystallization in Porous Media* (Tróia, Portugal), *Natural Stone Research and Heritage Stone Designation* (Vienna, Austria), the EGU General Assembly Vienna 2012 *Monuments under Threat* and the *International Conference on Built Heritage 2013: Monitoring Conservation Management* (Milan, Italy) were held. Besides the proceedings, which usually result from such conferences, numerous other publications on stone and stone buildings regularly find their way into the public domain. Not least amongst these are a number of Geological Society Special Publications (SP) including SP205 *Natural Stone, Weathering Phenomena, Conservation Strategies and Case Studies* (Siegesmund *et al.* 2002), SP271 *Building Stone Decay: From Diagnosis to Conservation* (Přikryl & Smith 2007), SP331 *Limestone in the Built Environment: Present-Day Challenges for the Preservation of the Past* (Smith *et al.* 2010) and SP333 *Natural Stone Resources for Historical Monuments* (Přikryl & Török 2010). This current volume, SP391, seeks to bring to the attention of the various professionals in the field – geologists, architects, engineers, conservators and conservation scientists – recent work centred on the characterization and performance of this important resource, and its use in historic buildings. This volume has wider relevance, including to those interested in the heritage of stone.

The continuing interest in the subject results from the fact that building stone is often one of the most defining features of the built environment and impacts not only on the aesthetics of our cities but also upon the cultural environment. Cities are often defined by the stone used in their construction: Aberdeen in Scotland, for example, is often known as the 'Granite City' or the 'Grey City', which reflects the extensive use of locally quarried grey granite in its buildings, monuments and statues. Similarly, Petra (Jordan) is known as the 'Rose City' (or 'Lost City of Stone') owing to the distinctive colour of the sandstone from which it is carved.

The historical use of stone related primarily to the proximity of the material resources to the places where these were needed and the ease of transport. Most stone was sourced locally. This does, of course, mean that in some areas legacy problems are encountered. For instance, the locally available stone might be subject to significant

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deterioration. Natural causes of deterioration, such as salts and frost, have been exacerbated by anthropological emissions. In (in)famously polluted areas, such as Venice and Athens, damage to archaeological and historical marble monuments has been widely publicized, and the processes and mechanisms involved have been widely studied and published, with the first targeted research happening in the 1980s and 1990s (Gauri & Holdren 1981; Guidobaldi 1981; Amoroso & Fassina 1983; Brimblecombe 1988; Caner *et al.* 1988; Charola 1988; Sabbioni *et al.* 1996; Camuffo *et al.* 1997). Such studies continue, although legislation and regulation of emissions have now led to an improvement in the situation.

Through the ages, however, the use of stone has by no means been fixed in either the areal or the temporal sense. The main historical driver for the use of local stone was the difficulty, or even impossibility, of transporting stone over great distances to the point of use, as well as the cost. In some cases, local supplies of stone were worked out or the resources were built over, forcing a change in supply patterns. As transport networks developed, the opportunities to use stone from greater distances increased, and stone of a much greater variety of colour, texture and physical properties became available to designers and architects. This, in turn, meant that the use of stone became subject to the vagaries of trend and fashion.

Economics also plays a major role in the use of stone. This is witnessed by the extensive seaborne import of low-cost stone for use as paving setts to Europe from China. Thus, the pattern of stone use over time has gone from being almost entirely local to one that is global as a product that transcends both regional and national boundaries. Clearly, there are notable exceptions to this: Stonehenge near Salisbury in SW England, for example, comprises monolithic local sarsens and 'blue' stones that are widely believed to have been transported from the Preseli Hills in SW Wales, over 250 km away (John 2008). The Romans were also famous for extracting coloured marble from all of the territories under their control and moving them with great efficiency all around the Mediterranean, and even as far away as the British Isles (Lazzarini 2007).

In this volume, the historical use of different stone types in Spain is highlighted by **Pereira & Cooper (2013)**. The authors describe the use of granite in Salamanca, and highlight the historical evolution of stone types as accessibility to alternative resources improved as a result of the development of transport networks. The importance of using the original material for repair and restoration purposes is also discussed, and the consequent necessity of maintaining access to a supply of the original building material is also noted.

A search for new stone resources is discussed in the paper by **Turmel *et al.* (2013)**, with reference to the ongoing restoration of Reims Cathedral (thirteenth and fourteenth centuries) in NE France, one of the great Gothic cathedrals and a UNESCO World Heritage Site. The recent closure of the last of the quarries of the local Courville stone (a Lutetian limestone) has resulted in a search for new resources. Five local disused quarries were identified as possible sources for replacement stone. As the properties of the tested stones were not exact matches with the original stone, further work was needed to identify the types of stone used, as well as further testing of other facies from several local quarries to find the best replacement stone for restoration.

De Kock *et al.* (2013) highlight once again, this time in France, the perennial problem of finding the 'right' stone to repair/replace historical buildings and monuments. Whilst the public and, often, conservation authorities require a good aesthetic match, the engineering requirements for a good match are far more complex and extensive. Colour, texture, grain size, bedding, mineralogy, induration, impurities, weathering rates and patterns, for example, all have to be considered, alongside the economics (e.g. price, availability and distance) for attaining the 'best' replacement stone with long-term 'match' characteristics.

One particular type of building stone used traditionally in southern Italy (Puglia region), the 'pietra gentile' (gentle stone) is described in the paper by **Calia *et al.* (2014)**. The paper focuses on the stone's resources, characteristics, use and decay patterns within buildings within many historical towns in the region, including both monuments and minor buildings. This information was gathered through both fieldwork and laboratory analyses.

Even using solely local stones, a large variety of materials can, however, also be found in historical buildings. **Fratini & Rescic (2013)** catalogue the building stone materials of the region of Tuscany in Italy that reflect the complex geology of the area. The variety of these materials determines the unique identities of the towns and villages of the region.

Similarly, the geology of the county of Cornwall in the UK is also complex. A rich variety of building and decorative stones were exploited from Neolithic times until concrete and brick became dominant in the twentieth century. **Bristow (2013)** provides a detailed review of these in his main paper and supplementary material, and emphasizes the importance of transport patterns for local use, and the development of a major nineteenth century granite industry and for roofing slate. Locally used stone ranged from loose granite boulders to

microgranite and even relatively weakly cemented beach sand known as 'sandrock', as well as much slaty mudstone and sandstone. Cornwall was a major mining area, so large quantities of waste stone from extractive operations were used in vernacular buildings and, in medieval times, in churches. Ornamental stone included unusual types of stone such as tourmalinized granite, basic hyaloclastite and serpentinite.

Cordiner (2013) discusses a survey of 180 churches built in West Sussex in England during the period AD 950–1850. A total of 51 types of stone were found, of which 30 were local and 21 imported. Identification relied on lithology, structure, texture, colour, weathering patterns, eroded fragments and fossils. The distribution of stone related to geological, geographical, economic, architectural and historical factors. The coastal plain is separated from a low-lying interior by a high ridge cut by several river valleys. Local stone was used to the north of the ridge and imported stone to the south. Local stone was taken southwards, and imported stone northwards, along the rivers. An exception was roofing and paving stone from the north, which was sold widely because of its scarcity. In early times, stone was recycled from Roman buildings, while Norman stonemasons favoured familiar imported stone from Caen.

The need to thoroughly understand the stone used in a building before conservation work is carried out is discussed in detail by **Calia *et al.* (2013)**. Extensive conservation work carried out on the Baroque limestone buildings of Lecce in southern Italy was accompanied by detailed studies on the stone's characteristics, resources, and associated decay and conservation problems. The research programme, carried out over a number of decades, may be regarded as an appropriate model for the study and management of preservation programmes related to built heritage.

Conservation issues are also discussed by **André *et al.* (2013)**. The authors here describe a multidisciplinary study designed to determine the effects of cement repointing on the rates of decay of sandstone used in medieval churches in the French Massif Central. It is made clear that the cost of poorly executed repointing is a substantial increase in the rate of decay and that this is simply not sustainable for historical buildings such as the Romanesque churches of the area studied.

The issue of water, especially driven rain that leads to the deterioration of many prominent old stone buildings like church towers and monuments, is the subject of the paper by **Laycock & Wood (2013)**. The authors describe experimental methods that allow for quantification of the diverse routes of direct ingress of rainwater into solid masonry, including its binding mortar and covering renders, in terms of moisture penetration and absorption. This is followed by similar estimates of water penetration subsequent to different repair works using various grouts, sealants and covering renders, so that optimal repair methodologies can be identified for each building situation.

Overall, historical buildings and structures in a particular area may be dominated by a single type of stone or by a variety of stones, depending on the diversity of the local geology. However, even in ancient times, some stone might be brought from further away for cultural or aesthetic reasons. With improving transport, especially since the mid-nineteenth century, a greater diversity of stone became available from further away, and was used in both new and existing buildings. The working out of the available materials, or the sterilization of the remaining resource due to development or because of planning constraints, of some local types of stone made it inevitable that alternative stone types were used for repair and maintenance of some existing structures. Nonetheless, in many cases, conservation authorities have required either use of the original stone or one that is aesthetically very similar. However, the suitability of stone depends on technical properties, not just aesthetic compatibility. Some types of stone have deteriorated relatively rapidly, either because they were not really suitable as building stone or because of the effects of a natural chemical reaction with rainwater or pollution, which dictated the use of an alternative stone for repair. Also, the difference between the original mortars and those used for repair, if inappropriately selected and applied, may lead to deterioration. It is important, therefore, that there is a sound knowledge of properties and a proper analysis of technical specifications and visual compatibility; especially before construction or restoration work is undertaken.

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