A non-destructive method for fixing placards with masonry structures

L Bianco[1,2*] **and A Bianco**[3]

[1] Faculty for the Built Environment, University of Malta, Msida MSD 2080, Malta
[2] Faculty of Architecture, University of Architecture, Civil Engineering and Geodesy, Sofia 1164, Bulgaria
[3] Faculty of Engineering, University of Malta, Msida, MSD 2080, Malta

* lino.bianco@um.edu.mt, alessandra.bianco.19@um.edu.mt

Abstract. It is common practice for government agencies to fix signs – and indeed even official temporary notices – onto masonry structures using steel nails. This method of fixing is destructive; it causes irreversible damage to the material fabric, which has a bearing on the overall aesthetic of the building, a scenario which is more acute if the site is of cultural heritage significance. Stones and concrete blocks (locally referred to as concrete bricks), the latter introduced in the 1950s, are the main materials used in masonry construction in Malta. Clay bricks are not utilized, as in Malta there is a blanket prohibition on the extraction of local clay. The main building material used in Malta since time immemorial is Lower Globigerina Limestone. This article puts forward the case for a non-destructive, reversable method to fix notices to building which respects the integrity of the dimension stones. Instead of being hammered into masonry blocks, the proposed removable plugs are installed in the mortar. Their size is relative to the thickness of the mortar bed and the load they are designed to carry, the latter being of negligible importance in the case of lightweight placards. The proposed solution applies equally to other masonry structures, whether erected in dimension or randomly placed stones, concrete blocks or clay bricks, as long as the construction in question uses mortar in the joints between the units.

1. Introduction

A now dated, but still valid, technical report on stone conservation was authored by James Clifton of the National Bureau of Standards, USA [1], a few years prior to the main comprehensive textbook on conservation by Bernard Feilden was published [2]. Citing a publication issued by the Building Research Station with respect to susceptibility of ferrous materials in the original construction of built heritage to corrode and thus induce cracking and subsequent spalling of stonework [3], Clifton called for the use of non-corroding materials such as epoxy-coated steel [4] and non-corroding non-ferrous alloys [3]. In reviewing man-made causes of decay, Feilden discusses damage caused by vibration and atmospheric pollution. In addressing special techniques of repair and structural consolidation, he tackles drilling techniques, notably drilling works and grouting [2]. This paper will address the practice of fixing placards – whether commercial advertisement signs, posters and billboards, or official notices – to masonry structures using steel nails. This is in fact the method used when posting

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

official notices of development applications submitted to the planning regulator in Malta, the main island in the Maltese Archipelago (figure 1a). This practice is destructive and causes irreversible damage to the building fabric, as well as having indisputable aesthetic impacts, especially problematic with culturally significant heritage buildings. Based on a qualitative overview of heritage value typologies covered by leading publications (notably by Mason [5], Yung and Chan [6], de la Torre [7], Doğan [8], Chen and Li [9] and Olukoya [10]), the most important markers of the heritage value of a building is its aesthetic/artistic qualities, followed by its historic, cultural/symbolic, social/community and economic value [11].

The Maltese islands support a building tradition spanning five and a half millennia. Its oldest pre-historic neolithic and megalithic temples were included in the UNESCO's World Heritage List in 1980 "*not only because of their originality, complexity and striking massive proportions, but also because of the considerable technical skill required in their construction*" [12]. With a superficial area of circa 316 km^2, Malta and its dependencies represent the smallest EU Member State and, at the same time, the nation state with the highest density of designated World Heritage sites. Its capital, Valletta, was also listed by UNESCO in its entirety as a World Heritage Site in 1980 [13] (figure 1b). It is one of the most concentrated heritage areas on the globe – 320 cultural monuments within an area of 55 ha inclusive of the St John's Co-Cathedral and the auberges of the Hospitaller Order of St John. This city, founded in 1566, is primarily constructed in Lower Globigerina Limestone (LGL), described by the English poet Samuel Taylor Coleridge (1772–1834) in 1804 as a "*sand-free stone*" [14]. It is "*remarkable for its softness; it is worked easily, but it is not strong enough against moistures* [sic] *and the sea-breeze*", an observation included in a publication issued in Lyon in 1536 authored by Johannes Quintinus D'Autun (1500–1561) [15]. Figure 2 illustrates the typical practice of using steel nails on cultural heritage buildings, in this case to post a notice of a planning application in Valletta. The main objective of this paper is to put forward a prototype plug to fix signs onto masonry which does not cause irreversible damage to the material fabric and thus it respects the integrity of the dimension stones notably of cultural heritage significance.

Figure 1. The Maltese Archipelago: (a) the main habitable islands; (b) Valletta, including the location of St John's Co-Cathedral and the auberges of the Hospitaller Order of St John (© Google Earth). Location of case study shown in figure 2 is circled in green.

2. Globigerina Limestone Formation

2.1. Lithostratigraphy

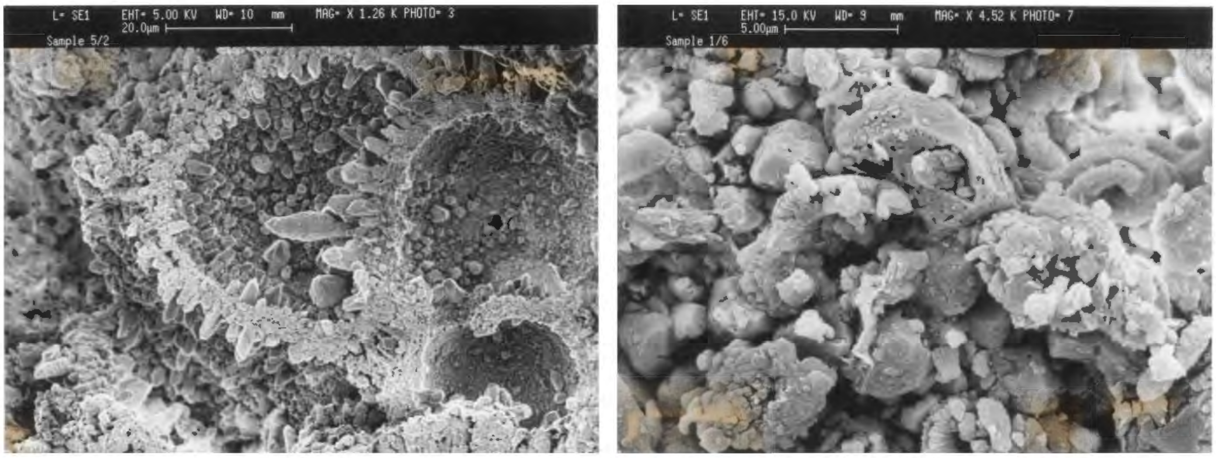
Lower Globigerina Limestone (LGL), the oldest member of the Globigerina Limestone Formation, is Aquitanian in age (23 million to 20.4 million years ago) [16, 17]. A comprehensive description of its lithostratigraphy is given in Baldassini *et al.* [18]. It is composed of massively bedded, biodetrital limestone consisting of globigerinid planktonic foraminifera. In contrast with the upper part of this member, the lower part is coarser-grained and strongly bioturbated. Pectinid bivalves and echinoids such as Schizaster are present in the former, and bryozoans and the echinoid Scutella in the latter [18, 19].

Figure 2. Development planning application at 99 Archbishop's Street on the corner with 81 Bakery Street, Valletta. Streetscape along (a) Archbishop's Street and (b) Bakery Street with site notice indicated by the authors in red and yellow markers respectively [20]; site notice (c) as on 12 January 2022 [20], and (d) detail marked in (c) as on 12 October 2022 – note the rusting steel nail.

In the building trade, LGL is graded in terms of first- and second-quality lithotypes. Good or first-quality LGL has a characteristic resonant vibration – it 'rings' on being struck with a hammer [21]. The inferior second-quality LGL, known as '*sol*' (also written as '*soll*') occurs in two varieties: sol aħmar (red sol) and sol ikħal (blue sol); the former is used in the building industry, often at a height of at least 1.2 m above the damp-proof course. In this paper, inferior LGL refers to sol aħmar.

2.2. Petrophysical characteristics

Microphotographs illustrating the texture, cement fabric and pores of both LGL lithotypes, studied using a Hitachi S-520 scanning electron microscope (SEM), are reproduced in figure 3. The first-quality lithotype has well defined physico-mechanical interlocking; its pore structure and fine-grained sparry calcite, which fills the inter-particle voids, cements most allochems (figure 3a). This interlocking physico-mechanical bond, pore structure and fine-grained cement account for its better durability compared to the second-quality lithotype (figure 3b).



(a) (b)

Figure 3. SEM images illustrating the pore structure, physico-mechanical interlocking and fine-grained sparry calcite cement in (a) the first-quality lithotype and (b) the second-quality lithotype [22].

With respect to LGL, the uniaxial compressive strength in its dry and saturated state is in the range of 15 N/mm^2 to 32.9 N/mm^2 and 9.1 N/mm^2 to 16.3 N/mm^2, respectively [23]. For inferior LGL, the mean dry compressive strength (f_k) is characteristically higher and porosity is lower [24]. In the terms set out by the Centre Technique de Matériaux Naturels de Construction [25, 26], LGL is unquestionably not a hard stone ($f_k > 40$ N/mm^2); some lithostratigraphic beds may be considered compact (10 N/mm^2 $< f_k \leq 40$ N/mm^2) rather than soft stone ($f_k \leq 10$ N/mm^2).

3. Proposed design solution

3.1. The issue

Where nails have been used to fix something to the surface of a building, there are two options when the item is due to be removed: (i) remove the nail or (ii) drive it further in. The former case, which is the most common, involves driving a cat's claw or hammer claw under the nail's head and levering it out. The latter case is more damaging in the long term, as additional stresses are generated due to corrosion of the nail.

Although nails have a narrow end, the pullout force (F_p) required to pluck them out of LGL generates a combination of tensile and shear stresses, resulting in a cone of the fabric being removed. F_p is directly proportional to the compressive strength of the limestone (σ_m) thus:

$$F_p = \sigma_m a_c \tag{1}$$

where a_c is the surface area of the conic frustum.

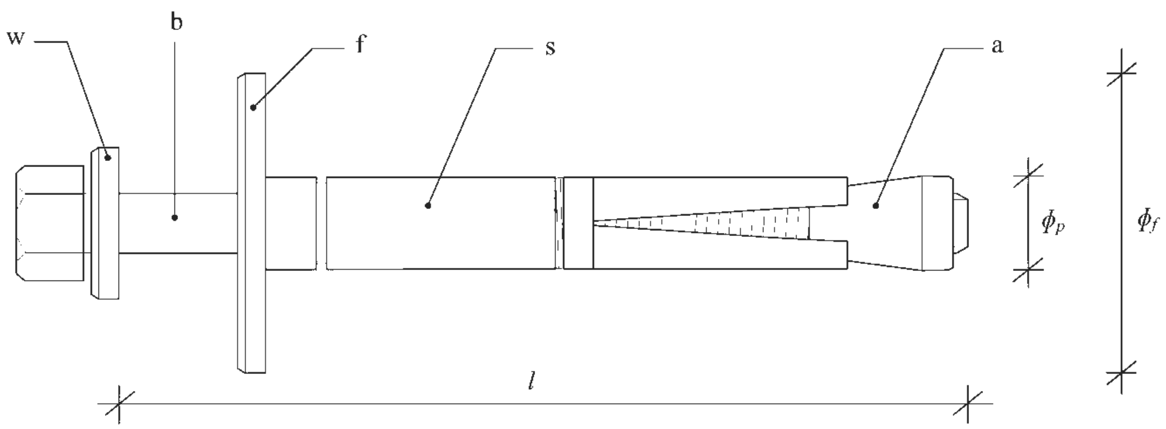
The greater the pullout resistance, the greater the pullout force, resulting in a conic frustum with a larger surface area, resulting in greater irreversible damage to the fabric. Furthermore, given LGL's physico-mechanical characteristics of interlocking and the fine-grained sparry calcite cement (figure 3), the surface area of the conic frustum generated in the first-quality lithotype is greater than in second-grade limestone. Therefore, more damage is caused to cultural heritage buildings predominantly constructed from the high-grade lithotype.

3.2. *Design proposal*

Historical masonry buildings erected in LGL dimension stones make use of lime-based mortar to level and fill in the spaces between the blocks [27]. The thickness of a mortar joint in such building construction is approximately 5 mm. The performance of the mortar is based on the relative bulk density and the 'free lime' content [28]. Lime-based mortar is not used to cement the joint but to provide a cushion between the blocks.

The design proposed in this study is an anchor plug which is placed in a hole drilled in the mortar of bed and/or head joints and can be removed when required. The concept is based on Rawlbolt®, the popular expanding shield anchor bolt widely used in the building industry. Named after John Joseph Rawlings (1860–1942), this proprietary general-purpose bolt is typically used to a recommended torque, depending on masonry type, where significant load-carrying capacity is required. This is not the case in this study, where the fixings are lightweight. When installed in masonry, Rawlbolts® generate a combination of tensile and shear stresses.

The proposed design – the RR-Plug – is a removable and reusable stainless steel plug with an expanding sleeve, a ferrule with a built-in flange and an angle-tapered nut, the latter ensuring maximum expansion on tightening the bolt (figure 4). The drill bit is slightly larger than the shield of the plug and can therefore be loosely placed in the hole ($\phi_h > \phi_p$, where ϕ_h is the diameter of the blind hole in the mortar and ϕ_p the diameter of the plug) once it has been cleared of debris. Once fully assembled, when the bolt and washer are tightened, the tapered nut is pulled towards the plug's shield via the bolt's thread; the angle-tapered nut does not lock in the shield on tightening. This expands the shield, securing the plug in its orifice. For extraction, the bolt is untightened and gently hammered in so that the nut angle moves away from the shield. The purpose of the inbuilt flange is to minimize and absorb most of the stresses transmitted to the masonry in which the plug is set (when it needs to be gently hammered to extract it). On hammering, the flange helps minimise the damage to the surrounding fabric (ϕ_f, the diameter of the flange, must be at least $3\phi_p$).



b : bolt
w : washer
f : ferrule with in-built flange
s : shield
a : angle-tapered nut

ϕ_p : overall diameter of RR-Plug
ϕ_f : diameter of flange
l : length of RR-Plug

Figure 4. Conceptual sketch of proposed design of RR-Plug (not to scale). The RR-Plug's main components include a bolt and washer, a shield (which includes a ferrule with a built-in flange) and an angle-tapered nut.

On hammering, the stress, σ, generated on the fabric is given by:

$$\sigma = F_h\ a^{-1} \tag{2}$$

where F_h is the hammering force and a is the area on which the F_h is transmitted.

The surface area of (i) the flange (a_f), (ii) the mortar joint covered by the flange (a_m) and (iii) the drilled hole (a_h) are related as follows:

$$a_f = 0.25\ \Pi\ \phi_f^2 \tag{3}$$

$$a_m \approx \phi_h\ \phi_f \tag{4}$$

$$a_h = 0.25\ \Pi\ \phi_h^2 \tag{5}$$

If the mortar is level with the masonry,

$$a = 0.25\ \Pi\ (\phi_f^2 - \phi_h^2) \tag{6}$$

and hence,

$$\sigma = F_h\ [0.25\ \Pi\ (\phi_f^2 - \phi_h^2)]^{-1} \tag{7}$$

If the mortar is recessed in the masonry,

$$a \approx \phi_f\ [0.25\ \Pi\ (\phi_f - \phi_h)] \tag{8}$$

and hence,

$$\sigma \approx F_h\ [\phi_f\ (0.25\ \Pi\ \phi_f - \phi_h)]^{-1} \tag{9}$$

Thus, in the case of Malta, if $\phi_h = 0.005$ m and $\phi_f = 0.015$ m, then the stress, σ, is over 50 % greater in recessed mortar than when the mortar is level with the masonry. Thus, it is recommended that prior to installation the mortar joint is rendered, with a reversible mix compatible with the existing fabric, to a relatively flat surface with the dimension stones in order to generate a uniformly distributed stress on the fabric when hammering.

4. Results and discussion

The installation and the eventual extraction of the RR-Plug each involve three stages, as set out below and illustrated in figure 5.

To install:

1. Drill a blind hole with a diameter equivalent to the thickness of the mortar and to a depth of at least 20 % longer than the length of the plug. Thoroughly clean the hole from debris (figure 5a).
2. Insert the RR-Plug in the cleaned blind hole until the flange of the ferrule is level with the surface (figure 5b).
3. Tighten the bolt (figure 5c).

To extract:

1. Loosen the bolt (figure 5d).
2. Gently hammer the bolt in (figure 5e).
3. Remove the RR-Plug (figure 5f).

After extraction, the hole must be thoroughly cleaned of any debris and infilled with a compatible mortar. In the case of LGL, lime-based mortar is compatible.

The hole can be drilled using a portable electrical drill. A drill of up to 0.5 hp is safe both in terms of damage to the fabric and health and safety; live electricity is a hazard in drilling work. If skillfully used, this kind of tool will cause less damage, but attention should be paid to the power of the drill. The principle is simple: the faster the rate of penetration, the more accurate the hole is likely to be [2]. High-speed rotary–percussive drills have a fast rate of penetration.

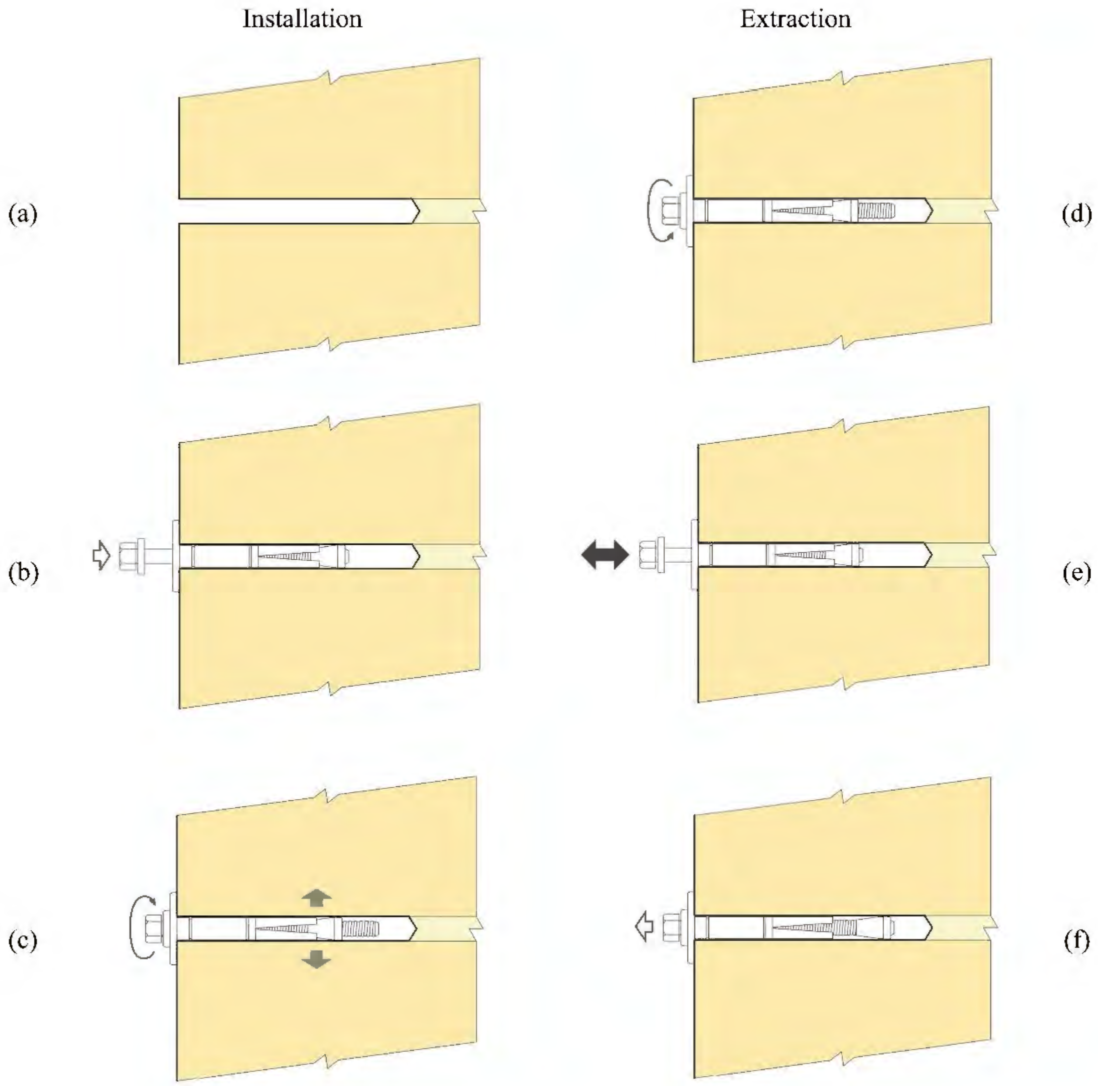


Figure 5. Installation (a to c) and extraction (d to f) guides of a RR-Plug (conceptual; not to scale).

It could be argued that this method is not fully non-destructive, as it does tamper with the mortar, permanently altering it in the affected area. However, in contrast with the current practice, this method does not affect the fabric of the dimension stones, and the mortar can be easily replaced with a compatible mix akin to the original – a common intervention in building construction.

5. Conclusions

Using nails to fix placards to the masonry of heritage buildings is a destructive practice which causes irreversible damage to the built fabric. An alternative method is to use a removable, reusable plug – the RR-Plug – which can be installed in a hole drilled in the mortar of the joints between the blocks. The size of the plug depends on (i) the thickness of the mortar joint (the dimeter of the shield must be slightly less than the thickness of the mortar) and (ii) the load/weight of the placard, which is usually negligible in the case of planning application notices affixed to buildings where works are proposed.

The installation of the RR-Plug is completely reversible without causing any damage to the masonry blocks, and it does not affect the geological fabric of the dimension stones. Although this method does impinge on the integrity of the mortar, a manufactured mix, it does not compromise the integrity of the matrix of the geological fabric. On extraction, the holes drilled for the plugs are infilled with a mix compatible with original mortar. In the case of LGL dimension stone, a lime-based mix should be used. This method can be used in any building constructed from masonry blocks with mortar joints, regardless of the stone used.

Philosophies of conservation, along with practices aimed at preserving the built environment have a long history within Europe, but they do change with the prevailing ideology of the times [29]. While conservation traditionally aimed to retain the memory of the past intact, current philosophy is grounded more in preserving values. The proposed method of using removable and reusable plugs to fix notices to buildings with mortar joints ensures that the heritage values relating to the building fabric of cultural monuments are respected. It eliminates the irreversible damage caused by the current practice and has no impact on the overall aesthetics of the monument.

The RR-Plug is not feasible to use in masonry construction with exceedingly thin mortar joints. Further research is required to develop a non-destructive method to fix signs in such construction whereby the installation and extraction technique does not impinge on the material fabric of the host dimension stones.

Acknowledgements
The authors would also like to thank Professor Inġ. Joseph Buhagiar (Head of the Department of Metallurgy and Materials Engineering, Faculty of Engineering, University of Malta), for his feedback on an earlier draft of this article.

References

[1] Clifton J R 1980 *Stone Consolidating Materials – A status report*. National Bureau of Standards Technical Note 118 (Washington: US Government Printing Office)
[2] Feilden B M 1982 *Conservation of Historic Buildings* (London: Butterworth Scientific)
[3] Building Research Station 1975 *Decay and Conservation of Stone Masonry*. Digest 177 (Garston, England: Building Research Station)
[4] Clifton J R 1976 Protection of reinforcing bars with organic coatings. *Materials Performance* **15**(5) 14–17
[5] Mason R 2002 Assessing values in conservation planning: Methodological issues and choices. *Assessing the values of cultural heritage: Research report*, de la Torre, M. (ed.) (Los Angeles: The Getty Conservation Institute) 5–13
[6] Yung E H K, Chan E H W 2013 Evaluation for the conservation of historic buildings. *Facilities* **31**(11-12) 542–564
[7] de la Torre M 2013 Values and heritage conservation. *Heritage & Society* **6**(2) 155–166
[8] Doğan H A 2020 Perception of the modern movement in architecture as cultural heritage. *Art History & Criticism / Meno istorija ir kritika* **16**(1) 65–78
[9] Chen D, Li J 2021 Process-led value elicitation within built heritage management: A systematic literature review between 2010 and 2020. *Journal of Architectural Conservation* **27**(1-2) 1-16
[10] Olukoya O A P 2021 Framing the values of vernacular architecture for a value-based conservation: A conceptual framework. *Sustainability* **13**(9) 4974
[11] Zammit N, Bianco L 2022 Computation of Heritage Values: Towards a holistic method to assess built heritage. *Heritage and Sustainable Development* **4**(2) 101–110
[12] UNESCO 1980 *Megalithic Temples of Malta* (https://whc.unesco.org/en/list/132/, retrieved 14 August 2022)
[13] UNESCO 1980 *City of Valletta* (https://whc.unesco.org/en/list/131/, retrieved 14 August 2022).
[14] Coleridge S T 1962 *The Notebooks of Samuel Taylor Coleridge*. 2nd ed.; Coburn, K., Ed.; Volume 1804–1808 (London:Routledge & Kegan Paul)
[15] Quintin d'Autin J 1980 *The Earliest Description of Malta* (Tas-Sliema, Malta: DeBono Enterprises)
[16] Giannelli L, Salvatorini G 1972 I foraminiferi planctonici dei sediment terziari dell'arcipelago

Maltese. I. Biostratigrafia dell Globigerina Limestone. *Atti Della Soc. Toscana Sci. Nat. Mem. Ser. A* **79** 49–74
[17] Felix R 1973 *Oligo-Miocene Stratigraphy of Malta and Gozo* (Wageningen, The Netherlands: H. Veenman and B.V. Zonen)
[18] Baldassini N, Mazzei R, Foresi L M, Riforgiato F, Salvatorini G 2013 Calcareous plankton bio-chronostratigraphy of the Maltese Lower Globigerina Limestone member. *Acta Geol. Pol.* **63** 105–135
[19] Foresi L M, Mazzei R, Salvatorini G, Donia F 2007 Biostratigraphy and chronostratigraphy of the Maltese Lower Globigerina Limestone Member (Globigerina Limestone Formation): New preliminary data based on calcareous plankton. *Boll. Della. Soc. Paleontol. Ital.* **46** 175–181
[20] Planning Authority 2022 *PA Case Details: PA/09046/21* (https://www.pa.org.mt/en/pacasedetails?CaseType=PA/09046/21, retrieved 12 October 2022)
[21] Bondin S 1992 Former President of the Softstone Quarry Association, Mqabba, Malta. Personal Communication
[22] Bianco L 2021 Geochemistry, mineralogy and textural properties of the Lower Globigerina Limestone Used in the built heritage. *Minerals* **11**(7): 740. https://doi.org/10.3390/min11070740
[23] Cachia J 1985 *The mechanical and physical properties of Globigerina Limestone as used in local masonry construction* (University of Malta, B E & A (Hons) dissertation)
[24] Bianco L 1993 *Some factors controlling the quality of Lower Globigerina building stone of Malta* (University of Leicester, MSc dissertation)
[25] Centre Technique de Matériaux Naturels de Construction 2015 *Study on characteristic compressive strength of natural stone masonry made with general purpose mortar* (Paris)
[26] Camilleri D H 2019 Malta's Heritage in Stone: From temple builders to Eurocodes 6/8. *MInt*, **31**(2): 49–67
[27] Bianco L, Cardona K 2020 Seventeenth-century building engineering in the central Mediterranean: a case study from Malta. *Terra Sebus. Acta Musei Sabesiensis* **12** 329–353
[28] Hughes J Q 1967 *The Building of Malta during the Period of the Knights of St John of Jerusalem, 1530–1795* (London, Alec Tiranti)
[29] Jokilehto J 1999 *A History of Architectural Conservation* (Oxford: Butterworth-Heinemann).