2025 IMEKO TC26 International Conference on
Metrology for Archaeology and Cultural Heritage
Bergamo, Italy, October 15-17, 2025

A matter of materiality: the use of multi-analytical methods for reinforcing urban heritage

Adi Sela Wiener[1,2], Laura Medeghini[2], Gabriele Favero[3]

[1] *Master's Program in Urban Design, School of Architecture, Bezalel Academy of Arts and Design, Bezalel St.4-14 Jerusalem, adisewi@gmail.com*
[2] *Department of Earth Sciences, Sapienza University of Rome, Piazzale A. Moro, 5, 00185 Rome, laura.medeghini@uniroma1.it*
[3] *Department of Environmental Biology, Sapienza University of Rome, Piazzale A. Moro, 5, 00185 Rome, Italy, gabriele.favero@uniroma1.it*

The Jerusalem cityscape is characterized by stone, the dominant building material that comprises the entire urban fabric, from buildings to street furniture, pavement to walls. Consequently, this material—stone—is identified as one of Jerusalem's attributes, and materiality as one of the city's values. As the city undergoes urban renewal processes including the demolition of historic structures, conservation challenges threaten Jerusalem's urban materiality. Responding to a recently published policy paper on the reuse of dressed stones, an issue not previously addressed, this paper proposes the implementation of a multi-analytical approach, specifically the application of methods used in archaeometry and conservation science on a macro scale of the urban environment. This proposed tool expands the information and data existing in the municipality's GIS in regard to Jerusalem stone, thus ensuring material compatibility in the historic city of Jerusalem and its urban heritage.

I. THE IMAGE OF THE CITY

Identified by many as *Umbilicus Mundi*, the centre of the world, Jerusalem's image is world-renowned. Whether experienced in person or through art and literature, the city's earthly-tangible image and its heavenly-intangible one both maintain a strong material appearance that derives from the mountains "round about Jerusalem" (Psalm 125: 2), from which its most ubiquitous building material (commonly called Jerusalem stone) was quarried (Figure 1). These stones have also been attributed with human qualities such as in Dan Almagor's (b. 1935) song "Jerusalem Stones" (1969): "[...] These are stones that surround and listen, [...] "Are the only stones that hurt" [1].

Since ancient times, construction throughout the city has been characterized by the use of stone, which dominates the Jerusalem cityscape. First and foremost were the massive and impressive construction projects of Herod the Great (c. 72 BCE – c. 4 BCE) of the Herodian Kingdom of Judea, including the rebuilding of the Second Temple and the expansion of its base, and other monumental stone examples such as the Walls of Jerusalem around the Old City [2, 3]. In 1918, a British Governance ordinance, set by Jerusalem's first governor, Sir Ronald Storrs, and known as the Stone Ordinance, ensured the prominent use of stone as a building material. Originally prohibiting the use of "inappropriate" materials, i.e., non-stone materials such as plaster and tin, the Stone Ordinance was later extended and modified to enforce the use of stone throughout the city by means of master plans and building schemes. This remains valid today, and includes the city Outline Plan No. 62 of 1959: "the exterior walls and columns of buildings and the façade of every wall bordering a road shall be faced with square natural ashlars" (Chapter 6, Section 1. Self-translation) [4, 5, 6, 7].

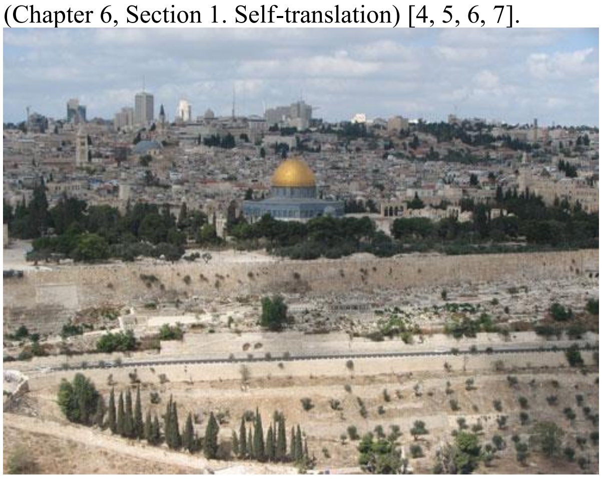

Fig. 1. Jerusalem from the Mount of Olives – Photograph looking westward. Courtesy of Yoav Avneyon www.yoaview.com

II. THE NATURAL ROCK AND THE URBAN MATERIALITY OF THE CITY

A. The natural rock

Sitting at 700-800 metres above sea level, the city of Jerusalem is located among the Jerusalem Mountains, which form part of the larger geographical unit of the Judaean Mountains. Geologically speaking, the city and its vicinity spreads largely over the Upper Cretaceous series, known also as the Late Cretaceous epoch (100.5–66 Ma).[1] In terms of petrography, this area is composed of carbonate sedimentary rocks, including mainly limestone, calcitic-dolostone (dolomite), dolostone, and marl and chalk and thin layers of flint to a lesser extent. Over the years, these rock layers provided the main building material for the city, resulting in a high compatible materiality between the natural environment and the built environment, called "Turonian Jerusalem" by Avnimelech [8, 9, 10, 11, 12].

Quarries were located within the city, near the construction sites where the stone was used, or in quarries in the city's immediate vicinity from which the building material could be easily transported [13]. Evidence of the natural bedrock, as well as evidence of ancient quarries that operated in the city centre and in other areas into which the city has spread, can still be distinguished today but is diminishing from the cityscape (Figure 2).

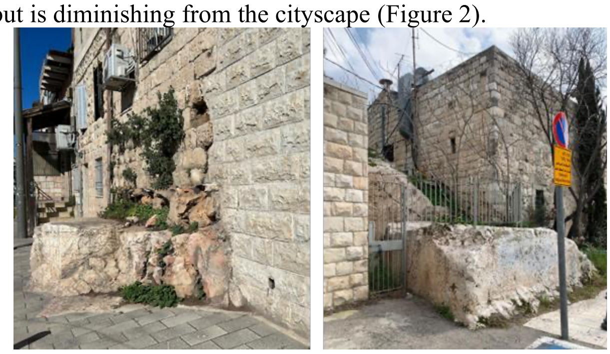

Fig. 2. Natural bedrock and evidence of quarries in the Jerusalem cityscape. Left: Bezalel St. Right: David Remez St. (Photos by Adi Sela Wiener)

B. The urban materiality

The entire spatial environment or urban fabric of the city of Jerusalem is comprised of stone—the buildings, structures, and the public areas, including the pavements and other elements—maintains a strong materiality, even acquiring the phrase "stony fabric" as offered by Edensor [14]. While mainly evident in the Old City and its walls, as well as in the Historic City of Jerusalem, which includes its first neighbourhoods built outside the walls starting in the second half of the nineteenth century and the beginning of the twentieth century, this stony fabric also characterizes the entire city. This built environment consists of horizontal components, vertical components, and street furniture that is mostly made of stone—built, paved, and cladded with primarily natural limestone and dolostone.

In order to understand the urban materiality of the city, research conducted between 2021 and 2024 investigated the material characteristics of the existing built environment and of the proposed built environment [15]. The collected data shows that the stone coverage of the existing built environment of the historic city is very high, i.e., in cases where the building coverage of the site is around 50%, the stone coverage on the horizontal components and the stone coverage on street furniture in the public space reaches 90-100% coverage, and the stone coverage of the vertical components reaches up to 80%. Similarly, data collected from planning initiatives for new construction as part of urban renewal processes in the historic city area shows that, in many of the initiatives, the stone coverage percentages of the various components are also very high: the percentages of stone coverage on the horizontal surfaces are 50-75% in initiatives that include a cultural heritage property set for conservation and about 50% in those that do not; in both cases the percentage of stone coverage on the vertical surfaces is high and stands at 75-85%, with some exceptions. Furthermore, by looking at the spatial interrelationships between the stone components—the horizontal, vertical, and street furniture—of the existing and the planned environments, they both form an almost continuous transition of stone materials, thus creating a distinct stony fabric. On the vertical surfaces the primary material is stone, and the secondary materials include glass, concrete, metal and/or aluminium, wood, and industrialized panels. On the horizonal surfaces, in contrast, the secondary material is garden soil and/or grass. All in all, the research shows that the urban materiality of the stony fabric will most likely be maintained. This in turn influences the specific characteristics and material compatibility that is required of the building stone, further detailed in building permits for the approval of the city conservation department.

III. MATERIAL IN CULTURAL HERITAGE CONSERVATION AND ANALYTICAL METHODS

Material and materiality are key concepts in cultural heritage conservation. Furthermore, the significance of materiality is closely connected to the primary occupation with the conservation of material culture artifacts and properties, the loss of materials, and the concept of authenticity. The fundamental principles of conservation include treatment of original materials, respect for existing fabric, mitigating losses and damage of the original materials, and reversibility [16]. Consequently, the study of materials, one of the main focuses of conservation science, is performed using various analytical methods. Knowledge of materials allows, among other things, for an understanding of the historical and cultural properties of a cultural site, as well as any former treatments that were

[1] The Late Cretaceous epoch, in turn, is divided into the Cenomanian, Turonian, and Senonian stages, according to the old division, or to six stages according to the new division (Cenomanian, Turonian, Coniacian, Santonian, Campanian, and Maastrichtian).

applied. Moreover, this information plays a major role in decision-making processes for determining the most suitable treatments during the conservation process. The analytical analysis methods are varied in their nature: they include both destructive and non-destructive testing that can be performed in situ (on the site itself), mostly in archaeological and historical sites, or in laboratories based on samplings of materials, or a combination of the two.

This study of the material characteristics of historic stone structures and buildings requires a multi-analytical approach, one based on both archaeometry and conservation science (also known as heritage science). In order to define the mineralogical, petrographic, and chemical composition of the stone, stone samples are analysed using several methods, in particular, Portable Microscopes such as USB microscopes and colorimeters, Optical Microscopy (OM), Fourier Transform Infrared Spectroscopy (FTIR), X-Ray Powder Diffraction (XRPD), and Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS). The combination of these methods provides a complete picture of the stone's composition [17, 18].

In expanding the reference to materiality, both materials and substance, along with design and workmanship, are part of the list of required attributes that express significant cultural values when seeking to assess the authenticity of a property. In this scale, it can be understood that the significance of materials at a macro scale is substantial for the conservation of the urban fabric's integrity, its authenticity, and as cultural identity, as this study demonstrates [19, 20].

IV. USING MULTI-ANALYTICAL METHODS ON THE MACRO SCALE TO STRENGTHEN JERUSALEM'S URBAN HERITAGE

The multi-analytical approach and methods described above are of great importance when dealing with a single heritage property. But can they also contribute to the understanding and management of a broader scale, i.e. the macro urban scale, and thus strengthen the urban heritage of a place where materials and materiality are considered prominent characteristics of that place?

In the case of the city of Jerusalem, stone was identified as a central attribute of the city's tangible urban heritage, and the materiality of the historic urban fabric as one of the city's values. The completed research proposes incorporating analytical methods as part of an impact assessment, formerly called a heritage impact assessment, with regard to the assessment of the built environment in areas of the historic city of Jerusalem that are subject to undergo urban renewal processes [15].

A. Sustainable Policy: Reuse of Dressed Stones

A policy paper published in September 2024 titled "Sustainable Policy – Reuse of Dressed Stones" by the city engineer (effective January 1, 2025) [21], makes the recommendation raised in Sela Wiener's research highly feasible to implement [15]. Moreover, this policy paper represents a significant paradigm shift in Jerusalem's conservation and heritage management. While reuse of the dressed stone had been done in the past, there was not a set written policy regarding the proper ways to reuse the dismantled stones. On account of this lack of a citywide, systemic framework, these attempts were largely ad hoc and often resulted in a misalignment with conservation principles and serious harm to conservation values. And while specific guidelines for certain applications of building with stone have been previously published, such as the Guidance for Stone Walls Design (2008), Spatial guidelines for historic buildings in the city of Jerusalem (2019), and Guidance for high rise building in stone in Jerusalem (2022), none of them addressed the aspect of building material reuse. Therefore, the new policy paper at the center of this paper's examination is the first to institutionalize the reuse of stone from a citywide perspective, explicitly connecting this reuse to the broader principles of sustainability. Its emergence reflects not only a growing global emphasis on the circular economy but also a formalized response to the challenges of managing Jerusalem's unique architectural and urban heritage in an era of accelerated urban development.

Driven by concern for a thorough, responsible, and intelligent use of environmental resources, and familiarization with the long-term durability and preservation of the building stone, the policy paper calls to reuse as much as possible the dressed stone in accordance with its original use. The policy paper also determines methods of action to maintain the uniqueness of the historic city's built environment, through the reuse of the original stone details that exist in historic buildings designated for external reinforcement or demolition as part of the process of regulating selective demolition and construction waste management. The articles below from the city engineer's policy paper are significant to the current paper (self-translation):

2. In requests to demolish or reinforce the exterior of a historic building or parts of a building, the city engineer or someone on their behalf must require reuse of the dressed stones of the existing building and stone paving since it contains architectural value.
3. The reuse will be done within the area of the lot that is the subject of the request, with priority given to walls and main façades facing the public domain. It is possible to transfer stones for reuse to other sites within the historic city.
6. The stones will be stored within the area of the lot. Transporting and storing stones outside the area of the site will require approval from the Conservation Department and the submission of monitoring reports.
7. In exceptional cases where reuse in the site cannot be allowed, the stones will be transferred in an orderly manner on behalf of the property owner to the Jerusalem

Municipality.

B. Proposed integration of analytical methods for the implementation of the policy paper

The following is a practical proposal to integrate the multi-analytical methods used in conservation science for the implementation of the policy paper. The proposal is listed as general guidelines, followed by a more detailed set of guidelines according to the type of interventions that are in line with city planning regulations:

- As a general rule, any historical site or building where an intervention is requested, i.e., modification to an existing structure, addition of floor or wing, or demolition of the existing building for the construction of a new building, it is required to submit a full documentation dossier as a condition for issuing a building permit. The dossier approval is a condition for a building permit approval.
- The full documentation dossier includes information about the history of the property, its architectural data, as well as an analysis of the site's values, and the attributes that convey those values. An engineering survey and a damage assessment survey are also required, as well as any additional surveys such as those regarding paint or murals. These detailed surveys require the integration of professionals who are experts in their fields, including engineers and conservators. The collected data is presented in the annexes of the dossier.
- The full dossier is uploaded to the municipality's geographical information system (GIS). This creates a property record that allows the information to be associated with the property's specific location, and for the data in the property record to become searchable, allowing spatial links within the urban environment.
- With regard to the significance of the building material in Jerusalem, it is proposed to add an annex that will exclusively deal with stone, in the same way the specific surveys mentioned above are added. It will include the features of stone, e.g., its original position on the various components of the property (stone walls, façades, openings, and unique architectural details) as well as a stone survey to identify the stone type and its general characteristics.
- The stone survey will be carried out with regard to the existing planning and regulatory system, and in accordance with the type of intervention proposed in the cultural property and through a combination of several types of analytical methods as further detailed below (Figure 3).

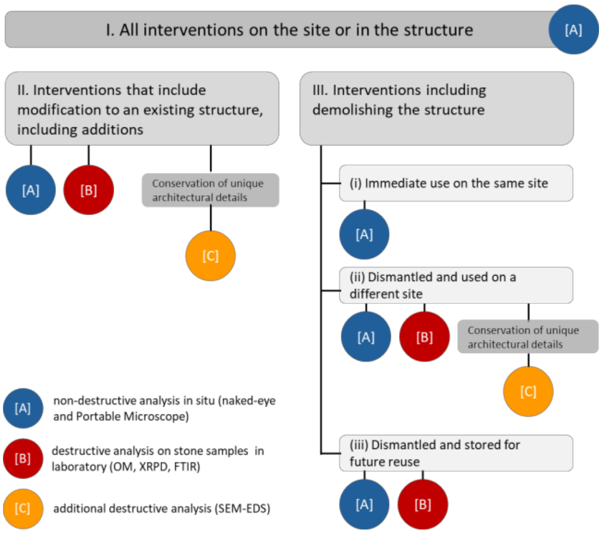

Fig. 3 Types of analytical methods in accordance with the type of intervention

C. The types of multi-analytical methods in accordance with the type of intervention

I. All interventions on the site or in the structure

- A preliminary non-destructive analysis will be performed in situ to provide initial information on the type of stone and its general characteristics.
- This may include:
  1. A naked-eye analysis to define the colour and macroscopic features.
  2. A Portable Digital Microscope (USB microscope Dino-Lite or colorimeter) to evaluate the macroscopic features of the surface and to assess possible discriminant optical features.
- The information will be incorporated into the special annex on stone in the documentation dossier, along with photographs and analysis, and will be uploaded to the property record on the municipality GIS.
- As long as no addition, modification, or demolition is requested on the site or in the structure, the information obtained from this non-destructive analysis will be sufficient.

II. Interventions that include modification to an existing structure, including additions

- The preliminary in situ non-destructive analysis detailed in part I will be followed by destructive analysis that is performed in a laboratory on stone samples extracted from the original structure.
- To the extent that it is possible to distinguish the use of different types of stone in the structure, then several stone samples will be taken, indicating the exact location of the sampling.
- The proposed list of analyses to be carried in the laboratory may include:
  1. Analysing thin sections of the stone samples using a polarized OM, which allows microscopic analysis

in both parallel (PPL) and crossed polarized light (XPL) to define the mineralogical and petrographic composition by elaborating microphotographs using supporting software.
2. Performing FTIR and XRPD analysis to allow further semi-quantitative information about the mineralogical composition of the samples.

- All data will be added to the already compiled annex of stone in the documentation dossier, expanding the information that was previously collected throughout the initial survey.
- As before, all the additional information will be presented in the property record on the municipality GIS, enabling a spatial representation of the distribution of stone types in the city's historic urban environment.
- The provided data will support the decision-making process, mainly determining the type of stone that will be used. The data on the mineralogical and petrographic characteristics will allow, in addition to the visual match that relies heavily on the colour of the stone and its shade, to determine the characteristics of strength, hardness, and durability over time, as well as to predict aspects of weathering and aging over time as a result of a response to climatic and environmental conditions.
- The implementation of the above decisions will be reflected in the inclusion of detailed instructions regarding the building stone in the building permit and in the technical guidelines that will guide construction.

In specific cases where interventions include conservation of unique architectural details, additional analysis such as SEM-EDS may be required. The SEM-EDS scanning electron microscope investigation on thin sections will be carried out, allowing definition of the samples' microstructure and the chemical composition of some inclusions to possibly highlight different microchemical features between different groups. In these cases, the gathered data will allow the selection of the specific type of stone required for the restoration and completion in the unique artistic treatment.

III. Interventions including demolishing the structure

- When the structure is slated for demolition, the building stone will be completely dismantled, allowing for the reuse of the stone.
- III(i): In cases where the dismantled stone will be stored on the same site for immediate reuse, only an initial in situ non-destructive analysis is usually sufficient.

  III(ii): In cases where the dismantled stone will be transported to a new site for reuse, a destructive analytical analysis detailed in section II must be performed upon dismantling on the original structure and on the structure in which the reused stone will be integrated prior to its reuse. Again here, in specific cases where interventions include conservation of unique architectural details, additional analysis such as SEM-EDS may be required. The data obtained from the stone sample analysis will allow for maximum material compatibility between the reused stone and the existing building material. Accurate records of the stones in both structures must be integrated into the property record.

III(iii): When the dismantled stone is slated for storage and future reuse in an unknown location, the destructive analytical analysis detailed in section II must be performed on the stone prior to its dismantling from the structure. All information should be presented in a clear way in both the storge area as well as physically on the stones.

In general, in all of the above cases, the data obtained from the various multi-analytical analyses regarding the type of stone, its characteristics, and its mineralogical, petrographic, and chemical composition will be uploaded to the property record on the municipality GIS. The information will be embedded in a layer explicitly dedicated to the Jerusalem stone, that can be superimposed on other information layers to allow for a comprehensive view of the stone types' material characteristics and spatial distribution in the urban environment.

V. SUMMARY

The characteristics of the built environment of the city of Jerusalem and its identified cityscape, as well as the values and attributes of its urban heritage, have a distinct material heritage based on stone as the main building material from periods past to present. Because the city's current urban renewal processes include the demolition of historical stone buildings, this paper refers to the recently published policy paper of the city engineer, "Sustainable Policy – Reuse of Dressed Stones." Based on a familiarity with multi-analytical methods that are commonly used in conservation science for individual objects, monuments and buildings, this paper challenges the conventional approach and proposes an innovative use of these multi-analytical methods to examine the broad urban scale. This use will enable the expansion of the information and data existing in the municipality's GIS in regard to Jerusalem stone, as well as to support the city engineer's policy from a perspective of material reuse and its adaptation to the high material compatibility that characterizes the cityscape of Jerusalem and its urban heritage.

With regard to aspects of implementation, it appears that from the time the policy paper came into effect in January 2025 until the time of editing the current publication, the policy's main principles are referred to in local conservation committee protocols. Furthermore, there is an additional directive, which is not included in the policy paper, to use the natural rock designated for quarrying in construction areas within the historic city as cladding for the new construction. While outside the scope of this paper, this offers another step in the efficient and sustainable use of natural resources.

REFERENCES

[1] D. Almagor, "My Jerusalem" [musical] (Hebrew), Kahn Theatre, Jerusalem, Israel, 1969.

[2] M. Ben-Dov, "Jerusalem through the ages: Atlas Carta," (Hebrew), Bloomsbury Academic, London, England, 1991.

[3] Z. Vilnay, "Encyclopedia of Jerusalem" (Hebrew), Achiever and Zmora-Bitan, Tel Aviv, Israel, 1993.

[4] A. Lobovikov-Katz, "The 'Stone Regulation' and Stone Building Conservation in Jerusalem (the Role of Building Material - Stone - in Urban Conservation)" (Hebrew), unpublished doctoral thesis, Technion - Israel Institute of Technology, Haifa, Israel, 2001.

[5] A. Ramon, "Jerusalem in the British Mandate time 1917–1948" (Hebrew), in A. Ramon (ed.), The Jerusalem Lexicon, Jerusalem Institute for Israel Studies, Jerusalem, Israel, 2003, pp. 52-54.

[6] O. Shalom, Y. Bouhsira, and A. Matar, "Under Cover: On the question of stone in Jerusalem" (Hebrew), Municipality of Jerusalem, Jerusalem Urban Design Center, and Bezalel Academy of Art and Design, Jerusalem, Israel, 2020.

[7] R. Storrs, "The memoirs of Sir Ronald Storrs," G.P. Putnam's Sons, New York, USA, 1937.

[8] A. M. Avnimelech, "Turonian Jerusalem" (Hebrew), Science, vol. 13, 1968, pp. 209-215.

[9] S. Ben-Yosef (ed.), "Shefela Foothills" (Hebrew), The New Israel Guide, vol. 11, Keter Press, Jerusalem, Israel, 2001.

[10] E. Mazor, "Geology with an Israeli hammer" (Hebrew), The Open University, Tel Aviv, Israel, 1976.

[11] L. A. Picard, "The Geological Situation of Jerusalem," in M. Avi-Yonah, M. (ed.), The Book of Jerusalem: The Natural Conditions and the History of the City from its Origin to the Destruction of the Second Temple (Hebrew), vol. 1, 1956, pp. 35–44.

[12] A. Sneh and Y. Avni, "Geological Map of Jerusalem," The Geological Survey of Israel, Jerusalem, Israel, 2011, partly revised 2016, https://www.gov.il/en/departments/general/jerusalem-map.

[13] A. Sasson, O. Sion, and L. Barda, "Quarry and Quarries in North Jerusalem During the Second Temple Period" (Hebrew), in E. Baruch, et al. (eds.), New Studies on Jerusalem, vol. 17, Ingeborg Rennert Center for Jerusalem Studies, Bar-Ilan University, Faculty of Jewish Studies, Department of Land of Israel Studies and Archaeology, Ramat Gan, Israel, 2011, pp. 265–286.

[14] T. Edensor, "Stone: Stories of Urban Materiality," Palgrave Macmillan, London, England, 2020.

[15] A. Sela Wiener, "City Scape Materials and Materiality. Redefining urban heritage materiality: a conceptual study of Jerusalem," unpublished doctoral thesis, Sapienza Università di Roma, Rome, Italy, 2025.

[16] ICOMOS, "Venice Charter," Second International Congress of Architects and Technicians of Historical Monuments, Venice, Italy, May 25-31, 1964, https://www.icomos.org/en/179-articles-en-francais/ressources/charters-and-standards/157-the-venice-charter.

[17] G. Artioli, "Scientific Methods and Cultural Heritage: An introduction to the application of materials science to archaeometry and conservation science," Oxford University Press, New York, USA, 2010.

[18] B. J. Smith, M. Gomez-Heras, and S. McCabe, "Understanding the decay of stone-built cultural heritage," Progress in Physical Geography Earth and Environment, vol. 32, no. 4, August 2008, pp. 439-461.

[19] ICOMOS Australia, "The Burra Charter. The Australia ICOMOS Charter for Places of Cultural Significance," Australia ICOMOS Incorporated International Council on Monuments and Sites, 2013, https://australia.icomos.org/wp-content/uploads/The-Burra-Charter-2013-Adopted-31.10.2013.pdf.

[20] UNESCO, "The Operational Guidelines for the Implementation of the World Heritage Convention," WHC 21/01, 2021, https://whc.unesco.org/document/190976.

[21] City Engineer, "Sustainable Policy – Reuse of Dressed Stones", Jerusalem, September 9, 2024, https://www.jerusalem.muni.il/he/residents/planningandbuilding/conservationofsites/policy_position_papers/