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ESSENTIAL OILS IN CULTURAL HERITAGE CONSERVATION IN INDONESIA: A METHOD, MATERIAL COMPOSITION, AND RESEARCH DEVELOPMENT

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Abstract:
Applied archaeological research, especially conservation in Indonesia, is really needed, considering that it is still relatively new, and historically, cultural heritage maintenance techniques have still focused on chemicals. The emergence of essential oils as conservation materials initiated by the Borobudur Conservation Center agency was the forerunner to the birth of scientific developments and research regarding care materials for cultural heritage and the use of local plants as inhibitors of the growth of biodeteriorating agents. The data in this paper focuses on a review of several studies that used local plants as conservation materials for cultural heritage made from brick, stone, and paper. Reflection in this developing long-term research is needed to create a protocol to use essential oils as a conservation material in every cultural heritage, which is a different material.

Keywords: Essential oils, cultural heritage, conservation

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1. Introduction

Indonesian archaeology reached its 113th anniversary on 14 June 2026, marking the establishment of the *Oudheidkundige Dienst* (OD) on 14 June 1913 as a permanent institution responsible for archaeological affairs at that time. Under the leadership of Dr. N.J. Krom, the OD was mandated to compile, register, and supervise archaeological remains and cultural heritage sites within the territory of the Dutch East Indies; to design and implement rescue measures to prevent the collapse of ancient structures; to conduct measurements and documentation of archaeological remains; and to carry out more intensive research activities (Soekmono et al., 2002).

Various efforts have been undertaken in Indonesia to safeguard cultural heritage up to the present day, particularly in the field of conservation (Amelia et al., 2024). These

efforts are not limited to promotional activities (Nugraha et al., 2021), filmmaking (Agustinova, 2022), and the revitalization of traditional games (Iryana et al., 2023), but also include preservation measures such as the construction of protective shelters, perimeter fencing, landscaping of sites, and zoning studies. These initiatives have further contributed to the emergence and development of Cultural Resource Management as a multidisciplinary approach to heritage conservation (Agus et al., n.d.) alongside increasing community participation (Prasodjo, 2000).

Several large-scale initiatives have played a significant role in the history of cultural heritage conservation in Indonesia. These include restoration and zoning studies of brick temples in Sumatra (Mulyati, 2012) research, zoning, and cluster development at the Sangiran site; the enactment of Law No. 11 of 2010 on Cultural Heritage and its subsequent legislation on Cultural Advancement; the post-earthquake restoration of Prambanan Temple following the 2006 earthquake (Pramumijoyo et al., 2009), and the restoration of Borobudur Temple, which spanned a decade and involved large-scale stone conservation of its structural components (Ismiono, 2017).

The complexity of the Borobudur restoration project did not solely focus on the reassembly of stone structures, the placement of Buddha statues, the reconstruction of stupas, or the arrangement of relief panels on temple walls, but also encompassed extensive conservation activities. The use of AC-32 material at that time (Samidi et al., 1997), represented a pioneering application of conservation materials for cultural heritage objects. Over time, however, the dominant use of chemical-based substances in cultural heritage conservation has been subject to criticism and re-evaluation. Various assessments of past conservation outcomes have encouraged new perspectives (Bakhri, 2021), promoting innovation through the use of plant-based materials for conservation treatments, particularly for cultural heritage affected by physical deterioration caused by biodeterioration agents (Swastikawati, 2013).

One of the materials which has come to dominate studies in Indonesian cultural heritage conservation is essential oil. Innovations in its application extend beyond the material itself, influencing formulation composition, application methods, material processing, and long-term monitoring strategies. Although research on the use of essential oils in cultural heritage conservation has been conducted for more than a decade, comprehensive reviews that compile methodological developments, material variations, and their disciplinary positioning within applied archaeology in Indonesia remain limited.

Current research on the use of essential oils as conservation materials is largely confined to experimental trials targeting biological deterioration agents of cultural heritage materials. Consequently, the role of essential oils in conservation practice remains at an early and exploratory stage, with insufficient assessment of their long-term material compatibility and applicability. Moreover, the predominant focus on antimicrobial efficacy in existing publications limits practical guidance for conservators attempting to develop and apply essential oil-based conservation treatments suited to local environmental and cultural heritage conditions (Reale et al., 2024).

In several field-based case studies, the local government agencies lacking sufficient field conservators are required to request assistance from expert teams affiliated with the Indonesian Heritage Agency (IHA) to conserve cultural heritage outdoors. In other field conditions, heritage site caretakers (*juru pelihara situs*) are unable to produce essential oil-based conservation materials independently and must procure them from specific institutions. Resulting in dependency and limited self-sufficiency in local cultural heritage preservation efforts.

The situation represents a particular urgency among conservators who remain dependent on chemical-based materials and conventional methods, especially given the complexity of deterioration processes caused by both physical weathering and chemical reaction of non-chemical conservation approach has been recommended by ICCROM in order to minimize risks to human health, the environment, and the cultural heritage objects themselves (Marco et al., 2023). In line with this perspective, the development of clear methods and standard operating procedures is essential, grounded in systematic studies and adaptive implementation of the conservation guidelines and proseduress proposed by ICCROM.

Therefore, this paper aims to elucidate the use and methods of essential oils in supporting cultural heritage conservation efforts in Indonesia, as well as to explore their prospective benefits from multiple perspectives, including cultivation, processing, extraction, and the potential formulation of standard operating procedures for the conservation of cultural heritage objects.

2. Method

In this paper, the authors conduct a literature-based study of several research outcomes related to the conservation of stone- and brick-based artifacts. The primary materials examined are essential oils derived from various spice plants originating from different regions of Indonesia. Studies concerning the use of essential oils are reviewed to identify the diversity of base materials, developments in conservation media formulation, the types of organisms responsible for the deterioration of archaeological objects, and the use of various additive compounds in the form of emulsion-based carriers applied during treatment.

This study employs a critical literature review approach by examining research on the use of essential oils in cultural heritage conservation in Indonesia conducted between 2014 and 2023. Studies utilizing essential oils in Indonesia, including those by Andriyani (2015), Stya (2017), Wahyuni et al. (2017), Hanifah (2018), Aryanto (2020), Ekarini et al. (2021), Wahyuni et al. (2021), Ekarini et al. (2022), Risna et al. (2023), are reviewed to assess variations in materials, methods, and applications on cultural heritage materials and biodeterioration agents, as well as to evaluate their contributions to heritage conservation treatment. This article aims to present a concise overview of the materials required for formulating conservation agents and to encourage further studies and the development of a standardized operating procedure (SOP) for the specific application of essential oils in the conservation of material culture in outdoor areas.

3. Results and Discussion

3.1. Parameters of authenticity in preservation

Departing from the Venice Charter of the United Nations as a form of international agreement adopted in 1972 concerning authenticity, which initially lacked a clear and explicit definition (Auffret, 2019), archaeological remains and historic buildings were subsequently designated as Cultural Heritage (Stovel, 2019). This discourse was further developed through an international conference convened by UNESCO in Thailand in 1994, which sought to elaborate on the meaning of authenticity in relation to archaeological heritage by introducing treatment approaches aimed at the preservation of cultural heritage. Point 1 of Chapter 9 on Values and Authenticity emphasizes the importance of maintaining authenticity through conservation practices (Lemaire et al., 1994), as stated below:

"Conservation of cultural heritage in all its forms and historical periods is rooted in the value attributed to the heritage. Our ability to understand these values depends, in part, on the degree to which information sources about these values may be understood as credible or truthful. Knowledge and understanding of these sources of information, in relation to original and subsequent characteristics of the cultural heritage, and their meaning, is a requisite basis for assessing all aspects of authenticity."

Despite its central role, conservation lacks a single, universally accepted terminological definition. Numerous definitions have been proposed by scholars, largely depending on the nature of the objects being preserved and safeguarded, and these cannot be directly equated with the treatment of museum collections. As long as the objective is to safeguard the authenticity of an archaeological object (Margariti, 2019), a wide range of techniques and interventions may be regarded as conservation efforts. Furthermore, historical values and emotional or belief-based attachments held by local communit may also be considered integral to conservation practices and the preservation of authenticity (Castriota, 2019). In the Indonesian context, such practices are supported by distinct scholarly frameworks and disciplinary approaches, many of which have been informed by international case studies. These include Cultural Heritage Management (OSCE, 2020), Disaster Risk Management (UNESCO, 2010), and Public Archaeology (Stringfellow, 2019).

3.2. The antiquity of essential oils in Indonesia

Essential oils have been used since ancient times in Egypt as one of the key components in the embalming of Pharaonic mummies, as well as in Persia and India over 3,000 years ago for aromatherapeutic purposes. The *Vedas* also mention the functions of aromatic substances in religious rituals and healing practices (Guenther, 1947).

In Indonesia, the use of essential oils can be traced back to the period of the Śailendra Dynasty. Archaeological evidence of such practices is depicted in the Karmawibhangga reliefs at Borobudur Temple, discovered in panels on the west Karmawibhangga, specifically in panels which are number 18 and 19, which portray scenes of a man receiving treatment from several women through head massage—possibly performed by *padadah* (traditional masseurs). Other reliefs illustrate individuals

providing care to a sick man by massaging his head (*papadah*) and applying medicinal preparations to his abdomen and chest (Aryani et al., 2020).

Figure 1. Reliefs in Borobudur Temple Compound, Carvings of The Activities of The Syailendra People Who Used Essential Oils to Massage Someone, edited by Rofi Surya Aryanto.
Source. Bhikku (2020)

In contemporary Indonesia, essential oils have become a major focus of research and development across various fields. In recent years, essential oil–based products have been successfully developed for use as perfumes (Ikarini et al., 2021), alternative livestock feed additives (Sanjaya et al., 2023), aromatherapy (Rizqa, 2022), fly repellents (Djarot et al., 2019), mosquito repellents (Gunawan et al, 2021), skincare treatments (Azizah et al., 2022), headache remedies (Rambe et al., 2022), air disinfectants (Dewi et al., 2018), hand sanitizers (Ermawati et al., 2023), food antioxidants (Sukandar et al., 2017), and antifungal agents (Febriyono et al., 2019).

3.3. Essential Oils in the Preservation of Cultural Heritage in Indonesia

Cultural heritage preservation efforts in Indonesia include conservation activities targeting heritage sites that directly interact with natural environments (immovable heritage). The use of essential oils represents an innovative approach in developing conservation materials aimed at inhibiting the growth of biodeterioration agents on cultural heritage sites affected by biological deterioration. Indonesia's geographical position along the equatorial belt provides favorable climatic conditions and a tropical environment rich in endemic plant species, which can be utilized as potential resources for cultural heritage conservation materials.

The initial idea for employing essential oils in heritage conservation is often attributed to a staff member of the Borobudur Conservation Center who participated in a workshop on essential oils in South Korea and subsequently collaborated with academics from Universitas Islam Indonesia. This concept was further developed by Riyanto, who identified several plant species with potential for use as conservation materials. These include clove (flowers or leaves), Illicium verum (star, bark), pine (bark, trunk, resin), sandalwood (bark, trunk, roots), eucalyptus (Melaleuca, leaves), ylang-ylang (flowers), cinnamon (bark), lemongrass (leaves), patchouli (leaves), Mentha arvensis (leaves), vetiver (roots), fennel (seeds), and wintergreen (Gaultheria, leaves) (Riyanto, 2014).

Subsequently, several studies have experimentally tested the potential of essential oils in cultural heritage conservation. Andriyani (2015) examined the effectiveness of nutmeg seed essential oil on stone-based cultural heritage materials and found that higher concentrations significantly inhibited lichen growth. Primastiti (2017) investigated the use of clove, vetiver, and agarwood essential oils, applied both individually and in combination, on wooden artifacts. The results indicated that clove essential oil exhibited the highest effectiveness compared to vetiver and agarwood oils, based on mortality rates and specific gravity measurements using bait paper tests. Mixed formulations demonstrated higher effectiveness at a concentration of 5%.

In the same year, research on essential oil applications was further developed by the Borobudur Conservation Center. This second-phase study, led by Wahyuni et al. (2017), utilized essential oils derived from patchouli, *Curcuma xanthorrhiza* (temulawak), clove, and nutmeg, in collaboration with Universitas Islam Indonesia. This research continued earlier initiatives (2014–2015) that promoted the use of traditional and natural materials in cultural heritage conservation. The results revealed that temulawak essential oil exhibited higher effectiveness than nutmeg, patchouli, and clove oils at equivalent concentrations.

Further research by Aryanto (2020) focused on the extraction of cinnamon bark essential oil as the primary active component, with brick-built temples colonized by mosses serving as the research medium. The study demonstrated that cinnamon bark essential oil at a concentration of 30% (the highest tested) successfully inhibited moss growth, as observed during monitoring on the second day, indicated by dark brown discoloration and a coarse moss texture.

Essential oils have also been shown to effectively control microbial growth on stone-built temples (Ekarini et al., 2021). This study employed essential oils derived from clove, citronella grass, and nutmeg, each at a concentration of 10%. The results indicated that citronella and clove essential oils were more effective in removing moss, while clove oil demonstrated higher efficacy in eliminating lichen on stone surfaces. In the same year, Wahyuni et al. (2021) further developed conservation applications using citronella grass essential oil.

In this latter study, concentrations of up to 10% were tested on both stone- and brick-built temples. Post-application monitoring after 48 hours showed that citronella essential oil effectively removed lichen, as evidenced by a color change from green to

brown, followed by desiccation. By 2023, essential oils continued to be a prominent focus in conservation research. Risna et al. (2023) extended previous approaches by not only formulating essential oil compositions to remove existing moss and lichen but also by targeting the prevention of regrowth on stone-built cultural heritage using a mixture of citronella grass, citrus peel, and ginger essential oils. The results demonstrated that this mixed essential oil formulation successfully prevented moss growth for up to one month.

Figure 2. (A) Spraying Method in Muarojambi Temple Compound (Brick Temple) and (B) Brushing Method in Plaosan Temple Compound (Stone Temple).
Documentation. Rofi Surya Aryanto

These studies exhibit distinct characteristics, with some emphasizing chemical compound analysis of essential oils, identification of biodeterioration agents affecting cultural heritage, and mineralogical analysis of the materials composing the heritage structures. Such methodological diversity reflects the varied academic backgrounds of the researchers involved. Differences in compound concentrations and formulations are influenced by factors including oil aroma, acid–base content, and oxidation effects on biodeterioration agents. Most of these studies have been conducted by researchers with backgrounds in physics and biology. However, the majority of essential oil research in heritage conservation continues to focus on short-term effectiveness, while studies addressing long-term impacts—such as material discoloration, chemical reactions, and sustained effects on stone and brick substrates—remain limited.

3.4. Variations in Material Manufacturing Methods

The preparation of materials in each study does not follow an identical formulation, even though certain stages in the preparation process have become relatively standardized. Various plant species have been selected based on random sampling, material availability, or local resource potential and regional commodities. In practice, the essential oils tested on heritage objects are not used in their pure form, as essential oils are volatile in nature (Berlian et al., 2023), and therefore require additional substances as carriers and solvents.

The development of essential oil–based formulations in conservation research is summarized in Table X below. Over the past decade, research on essential oils in the field of heritage conservation has demonstrated substantial methodological and compositional variation. In spray application methods, essential oil components that are

insoluble in water are commonly combined with Tween 80 as a binding agent (emulsifier) to facilitate the integration of water and essential oil phases (Kesumawardhany et al., 2016). These formulations generally maintain a balanced ratio between the solvent components and distilled water, while the proportion of essential oil varies according to the intended concentration.

In practical applications, a 1% essential oil concentration corresponds to 1 mL of essential oil, whereas the volumes of Tween 80 and distilled water are kept constant at 10 mL in each formulation. Essential oils mixed with Tween 80 and applied through spraying are typically intended for testing conservation agents on brick- or stone-built cultural heritage located outdoors or in direct contact with natural environmental conditions. In laboratory-based experiments, previously studied essential oil formulations have employed ethanol, methyl cellulose, and chloramphenicol as solvents or additives, often supplemented with alcohol. Laboratory studies commonly use microorganisms as test parameters, including bacterial assays conducted by Hanifah (2018), and microalgae tests reported by Wahyuni et al. (2017).

Table 1. Variations in Components of Essential Oils

Research	Main Component	Solvent	Addition
(Andriyani, 2015)	Nutmeg (*Myristica fragrans* Houtt)	Etanol	Aquades
(Wahyuni et al., 2017)	Patchouli (*Pogostemon cablin*), Ginger (*Zingiber officinale*), and clove (*Syzygium aromaticum*)	Etanol	Aquades
(Primastiti, 2017)	Vetiver (*Chrysopogon zizanioides*), clove (*yzygium aromaticum* (L.)), and aloes (*Aquilaria malaccensis*)	Metil Celulosa	Aquades
(Hanifah, 2018)	Ginger (*Curcuma xanthorrhiza Roxb*), patchouli (*Pogostemon cablin*), and clove (*yzygium aromaticum* (L.))	Alcohol and Chloramphenicol	Aquades
(Aryanto, 2020)	Cinnamon Bark (*Cinnamomun Burmanni*)	Tween 80	Aquades
(Ekarini et al., 2021)	Citronella (*Cymbopogon nardus* (L.) Rendle), nutmeg (*Myristica fragrans*), and clove (*Yzygium aromaticum* (L.))	Tween 80	Aquades
(Wahyuni et al., 2021)	Citronella (*Cymbopogon nardus* (L.) Rendle)	Tween 80	Aquades
(Ekarini et al., 2022)	Citronella (*Cymbopogon nardus* (L.) Rendle)	-	-
(Risna et al., 2023)	Citronella (*Cymbopogon nardus* (L.) Rendle), orange peel (*Citrus sinensi*), and starfruit (*Averrhoa bilimbi L.*)	Destilled water and Nigarin	Aquades

In more recent developments, essential oil formulations have been combined with distilled water, nigerin, and aquades to produce ready-to-use products. These products are formulated as water-based essential oil emulsions and include

standardized usage guidelines. A single 120 mL bottle is reported to be sufficient for inhibiting the growth of biodeterioration agents on temple structures under ambient temperature conditions of approximately 15–20°C.

3.5. Limitations and Challenges in Essential Oil-Based Conservation Practices In Indonesia

Although the use of essential oils as alternative materials in cultural heritage conservation has shown significant development, various limitations and challenges remain evident in both practical application and scientific foundations. Most existing studies tend to emphasize short-term effectiveness in inhibiting the growth of biodeterioration agents, while investigations into long-term impacts on heritage materials—such as stone, brick, wood, and paper—remain relatively limited.

On the one hand, the volatile nature of essential oils contributes to their antimicrobial activity; on the other hand, it raises concerns regarding material durability, performance consistency, and the need for repeated application over time. Another critical challenge relates to variations in material composition and application methods. Differences in plant species, extraction techniques, concentration levels, and the use of emulsifying agents frequently result in inconsistent outcomes across studies. Despite more than a decade of methodological development involving diverse plant species and varying concentration levels, several critical issues remain insufficiently addressed by researchers and conservators. The use of essential oils as conservation agents has yet to reach a consensus regarding standardized operational procedures. Furthermore, interactions between the active compounds of essential oils and the mineral or organic components of cultural heritage materials have not been thoroughly examined, particularly in relation to potential chemical reactions, residue formation, and their effects on visual changes and long-term structural stability (Pinna, 2025).

From an institutional and disciplinary perspective, essential oil–based conservation practices in Indonesia are still largely positioned as experimental or supplementary approaches rather than being fully integrated as primary conservation strategies. The absence of national guidelines or standardized operational frameworks limits broader acceptance and implementation among conservation practitioners. In addition, most studies continue to be dominated by natural science– and laboratory-based approaches, with relatively limited involvement of archaeologists in both the design and interpretation of conservation outcomes. This condition reinforces the perception of a disconnect between conservation practice and the broader disciplinary framework of archaeology.

These limitations underscore the need for strengthened interdisciplinary, long-term, and material-specific research. Future studies should be directed toward extended monitoring, the development of standardized testing protocols, and critical evaluations of material compatibility. Such efforts are essential to ensure that the use of essential oils is not only effective in temporarily controlling biodeterioration but also contributes meaningfully to the sustainable preservation and authenticity of cultural heritage.

4. Conclusion

The emergence of essential oils represents a distinctive breakthrough in the development of cultural heritage conservation studies in Indonesia. While, in a global context, the preservation of ancient objects through care and scientific techniques may be regarded as a long-established topic, the utilization of locally sourced Indonesian plants—formerly valued primarily as herbal resources for human use—introduces a novel and context-specific dimension. These plant resources have now become multifunctional materials with applications extending beyond traditional medicinal practices. For some audiences, this development may appear merely as a form of academic romanticism within applied archaeological research. However, when viewed from a broader perspective, the benefits extend beyond researchers alone. Local farmers may also gain tangible advantages, as they are no longer limited to selling raw plant materials but may increasingly participate as producers within the essential oil value chain.

Nevertheless, the position of essential oil–based conservation within applied archaeology, particularly in the field of heritage conservation, appears to be weakening. This is largely due to the tendency to frame scientific inquiry within rigid experimental outcomes—defined simply as success or failure. Consequently, limited attention has been given to the epistemological status of such research. Even within archaeological academia, the legitimacy of conservation-oriented studies is often questioned, especially when students express interest in pursuing conservation research. To date, studies in this area largely remain positioned outside the core domain of archaeological scholarship. Despite these challenges, multiple factors suggest that essential oil–based conservation research may eventually become more firmly integrated into archaeological science in Indonesia. As research paradigms evolve and interdisciplinary boundaries become increasingly permeable, conservation studies—particularly those grounded in local resources and sustainable practices—hold strong potential to be recognized as an integral component of archaeological knowledge production.

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