Article

Architectural Heritage Conservation in Nigeria: The Need for Innovative Techniques

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Abstract: Architectural heritage conservation in recent years has hinged on conventional methods and has failed to recognize innovative methods and emerging technologies. Consequently, in Nigeria, suboptimal conservation work results in the continual deterioration of architectural heritage, leading to the loss of heritage and its values and significance. The study, therefore, sought to examine challenges and prospects for implementing innovative techniques in the conservation of architectural heritage in Nigeria. The study examined three heritage conservation interventions in Nigeria, focusing on the applicability of innovative conservation methods for documentation, diagnosis, and treatment of deterioration of architectural heritage. Questionnaires were administered through purposive sampling to 40 heritage conservation professionals, with 31 (77.5%) completed and returned for analysis. A Cronbach's alpha reliability test value of 0.76 established the validity of the research instrument. The findings affirmed that heritage professionals have low familiarity (mean value of 2.19) with innovative techniques for conservation of architectural heritage. Of the respondents, 41.9% had gained a minimal level of technical knowledge of how to implement innovative techniques in conservation interventions. Improving the performance of conservation interventions also ranked highly as a potential strength of implementing innovative techniques. Conclusively, there is a need to improve advocacy and training in innovative conservation techniques based on their ability to characterize architectural heritage materials and investigate their chemical composition, microstructure, and morphological features.

Keywords: heritage materials; conservation; innovative technology; authenticity

1. Introduction

Architectural heritage of Nigeria encompasses buildings with cultural, historical, aesthetic, religious, or economic significance inherited from past generations. It consists of vernacular architecture, colonial architecture, Brazilian/Afro-Brazilian architecture, and post-colonial architecture. These buildings were constructed with a combination of artistry and craftsmanship in different parts of the country. Some of these buildings have been declared national monuments [1], while some are on the proposed list of national monuments. They are made of different materials, such as clay (including adobe), wood (timber), metal, brass, palm fronds, date palm, raffia, and stone [2]. The use of these materials in buildings stems from their availability in the locality where the buildings were constructed. Nigeria's architectural heritage is significant and valuable and, therefore, demands innovative conservation to preserve it for present and future generations.

The need to conserve Nigeria's architectural heritage arises not only from its significance but also because of its deteriorating state (Figure 1). Generally, materials used in the construction of heritage buildings are prone to physical, chemical, and biological decay caused by changes in climatic conditions, wind, water, and anthropogenic activities [3,4]. Other causes of damage include salt, fire, microorganisms, and insects [5,6]. The effects of these agents of deterioration are manifested as cracks and bulges; patina, surface, and basal erosion; crust formation; and fragmentation.

Figure 1. Deteriorated façade of Campos building, Lagos, Nigeria.

Conservation of architectural heritage in Nigeria is done jointly or individually by different stakeholders, which include government, individuals, and private organizations. These stakeholders apply the ICOMOS Charter [7] fully or partially during conservation, which entails gathering data about the history of the building, assessing decay, implementing the required treatment, and introducing control measures [8]. Despite this approach, the use of innovative methods is lacking in various conservation management plans for architectural heritage in Nigeria. Studies [9–11] have shown that the holistic use of innovative technologies as a complement to the traditional conventional methods boosts the efficacy of both methods for conservation purposes. The benefits of the proper application of traditional conventional methods lie in the principle of using materials that are of the same type as the deteriorated ones during conservation [12]. On the other hand, new technologies are useful for ascertaining the exact material structure and cause of decay and proffering ecologically friendly restoration techniques [13,14]. The need for the inclusion of innovative methods in the conservation management plan of architectural heritage in Nigeria is, therefore, vital.

This paper examines the challenges and prospects for implementing innovative methods for surveying, recording, and presenting data and information about the deterioration of architectural heritage, diagnosis of the causes of deterioration, and determination of the restoration methods to employ.

1.1. Conservation of Architectural Heritage in Nigeria

A multidisciplinary approach is used whereby appropriate experts and different stakeholders are involved in the conservation process from the outset [7]. The stakeholders include local communities, government organizations, such as the National Commission for Museums and Monuments (NCMM), community leaders, such as traditional rulers, and non-government organizations [15]. These stakeholders, through their ideas, knowledge, and skills, are meant to ensure that the built heritage is not only conserved but also that its values are preserved during conservation [16,17]. The values of heritage buildings should be perceived in the cultural context in which the architectural heritage exists and should be retained accordingly during conservation (Figure 2). Sabri and Olagoke [18] explain how the value-based approach helps experts and local communities where the built heritage exists to reach a consensus on the type of material to be used in conservation, but ICOMOS [7] has emphasized that conservation of architectural heritage is the combination of values and authenticity of the heritage, which is beyond the physical heritage and cannot be fixed. On the other hand, Ewemade and Osasona [19] have argued that the 'spirit and meaning' of heritage are born in the historical interaction of people

and community with the buildings. The cultural context of the architectural heritage is, therefore, considered a vital component in conservation. The community knows the value of the built heritage and explains this to conservators so that it will be retained during conservation.

Figure 2. Olayinka House, one of the architectural heritages located in Ile-Ife, Nigeria [19].

Conservation is necessitated by deterioration caused by leaking roofs, moisture, insect and microbial attacks, the dilapidation of drainage facilities, pollution, and inappropriate use [2,20]. Other factors are poor funding for proper maintenance, civilization and development, and neglect [21]. Decay arising from these causative agents is observed as crumbling plaster and paint, warping of doors, sagging of roofs, cracks, leakages, discoloration, exit holes, moist walls, and corrosion [18,22]. Apart from deterioration, conservation is also done to prevent occurrence of decay.

Omisore and Ikpo [21] examined the conservation work of different cultural properties in Ile-Ife, Nigeria. The researchers observed that repair/replacement of structural elements was the major treatment strategy applied. Ewemade and Osasona [19], in their study, also noted the potential benefits of rehabilitation as evidenced in intervention on Ile Olayinka in Ile-Ife. They suggested that such conservation processes should be done for all architectural heritage. In addition to rehabilitation, removal of biological growth and clearing of blocked drainages are also part of the conservation process [19]. The diagnosis of deterioration in the conservation processes examined by Omisore and Ikpo [21] and Ewemade and Osasona [19] were, however, conducted mainly by visual observation.

Despite the emphasis on innovative techniques by the ICOMOS Charter on the analysis, conservation, and structural restoration of architectural heritage, traditional methods of conservation are continually applied, which has resulted in various failures in conserving architectural heritage (Figure 3). Feilden [23] noted that documentation, diagnostic, and treatment stages are vital components of conservation of architectural heritage. Perito and Cavalieri [24] and Fais and Casula [14] examined conservation in the 21st century and submit that emerging technologies and methodologies are contributing to the successes of various conservation interventions implemented in Europe. However, Gbadegesin and Osaghale [15] revealed that innovative techniques are not employed in the documentation, diagnostic, and treatment stages of conservation, which results in ineffective and poorly managed heritage conservation in Nigeria.

Figure 3. Conservation works on cracks in the entrance stair of another architectural heritage, Ologbenla House, Ile-Ife, Nigeria [19].

1.2. Innovative Technologies in Architectural Heritage Conservation

Innovative technologies have been applied in the conservation of architectural heritage in developed countries with proven effectiveness [25,26]. Many of the techniques applied are non-destructive and are used for documentation, diagnostic, and treatment purposes. As explained by Fais and Casula [14], non-destructive conservation methods of architectural heritage help to obtain qualitative and quantitative parameters needed for the conservation process of the architectural heritage but they are time consuming and delicate. Sterflinger and Piñar [5] identified determining appropriate treatment methods as the main challenge in the conservation of architectural heritage.

ICE [27], Stylianidis and Remondino [28] and Zhao and Zhang [11] classified conservation processes into three methods. First, documentation methods involve a survey of the architectural heritage, recording the parameters needed for the conservation processes and visualization of the parameters recorded for communication with the conservation team. Second, diagnostic methods involve analysis of the recorded parameters and treatment of the decay. Third, treatment intervention methods involve different strategies for the restoration of the architectural heritage. Figure 4 reveals the details of the various innovative methods for conservation of architectural heritage.

1.3. Documentation Methods

Gulotta and Toniolo [29] assert that 'each historical object has its unique characteristics according to its physical condition and time'. Conservation processes of architectural heritage, therefore, involve the understanding of the histories, values, and significance inherent in the physical and emotional features of the heritage [7]. Therefore, in view to understanding the heritage, it is vital to gather data about the physical condition such as condition of the materials and investigate the chemical composition, microstructure, and morphological features of the heritage [30]. Mohd-Isa and Zainal-Abidin [17] described documentation of architectural heritage to include surveying, recording, and presentation of the data. Innovative methods for documentation of architectural heritage are, therefore, classified into image-based, non-image-based, and combinative methods, as revealed in Figure 5.
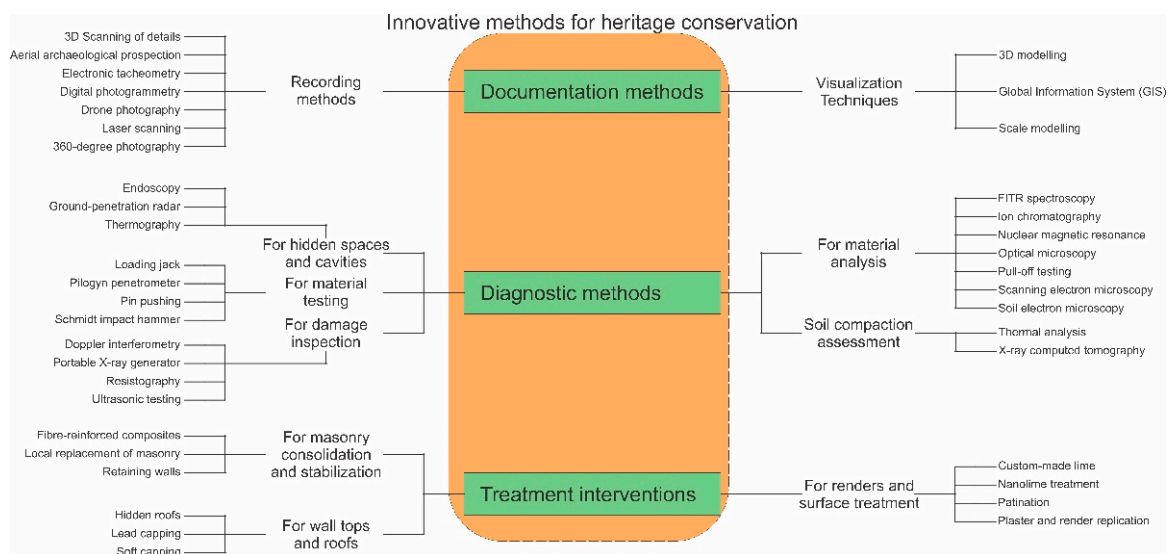
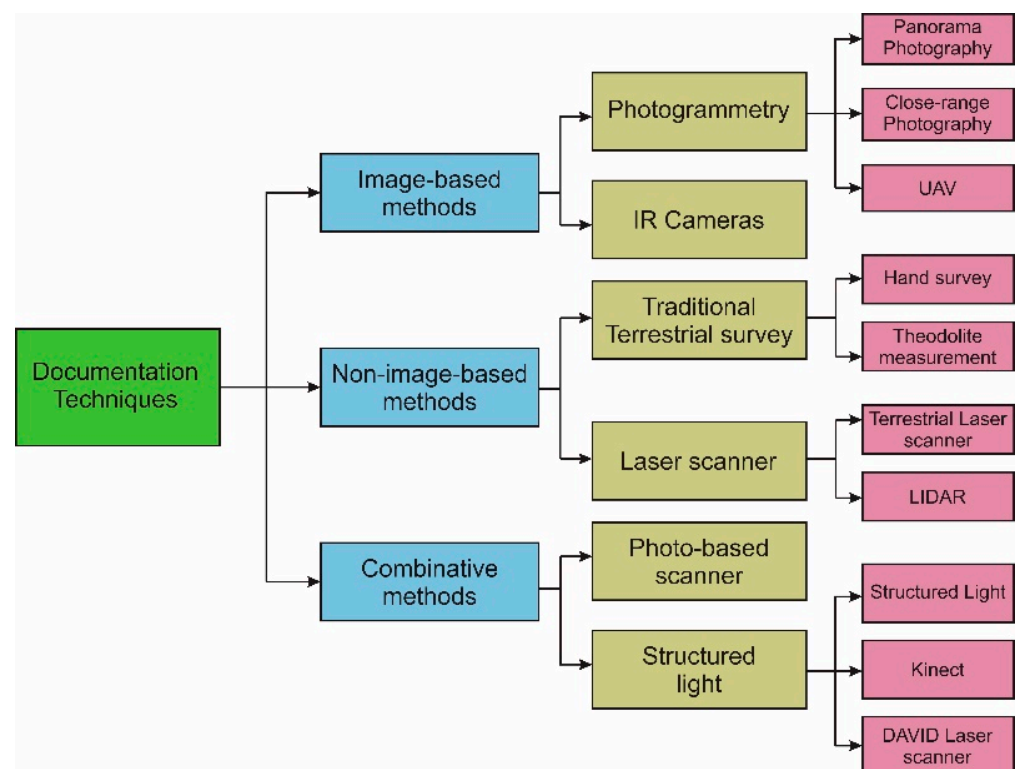**Figure 4.** Innovative methods in the conservation of architectural heritage. Adapted from ICE [27].

Figure 5. Categories of documentation methods adapted from Hassani [30].

In addition, ICE [27] categorized documentation methods into recording and visualization techniques (Figure 4. Hassani [30] described image-based techniques as methods based on production and archiving photographic data, which are used for interpreting, measuring, and modelling the architectural heritage. Non-image-based techniques, as well, produce images through separate processes that are not based on the surveying processes, while combinative methods take the advantage of image-based and non-image-based techniques.

1.4. Diagnostic Methods

Conservation of architectural heritage is preceded by proper assessment of its structural elements and material to determine the causes of decay and its degree as well as the appropriate conservation measure to be applied [10,29]. The preliminary assessment is done by visual observation, by which conservators and architects evaluate decay only with naked eyes without any instrument. Although this is the compulsory basic step, it does not give detailed information about past or ongoing deterioration, hence, the need for informative diagnostic tools.

Optical microscopy (OM) and scanning electron microscopy (SEM) has the potential to characterize heritage materials, detect potential biodeteriogens, and shows the spatial distribution of potential surface biodeteriogens [25,31]. Characterization of the material gives an insight into the type of stone used (for stone building), groin compartment, and pore size, all of which determines the susceptibility of architectural heritage to deterioration [14,32]. The work by Fais and Casula [14] and Adetunji and Essien [33] showed a multistep and integrated approach in the diagnosis of a decayed historical building. A 3D Terrestrial Laser Scanner was used to study the geomorphology of the stone used in the building, while ultrasonic measurement determined the thickness of the stone to ascertain its elasto-mechanical strength. Infrared Thermography was used to measure the temperature across the surface of the heritage. In the study, results of the OM and SEM revealed the type of stone, porosity, and presence of microorganisms.

The study by Urzì and De Leo [13] demonstrated the use of non-invasive and non-destructive techniques in carrying out the diagnosis. These techniques are advantageous because they do not destroy the underlying material [34,35]. Materials used in these techniques include adhesive tapes [35], nitrocellulose membranes [36], and sterile scalpel [37]. Environmental and biological parameters of the heritage, which favor the growth of biofilms, can also be obtained. Temperature and humidity are measured with a thermohygrometer [38], while a dust sensor is used to detect dust [39].

A Raman spectrometer is a vital and useful tool in the conservation of architectural heritage. It is used for in situ analysis to determine organic and inorganic substances on a stone substratum including conservation chemicals such as consolidants and water repellents. A Raman spectrometer is very useful when there is no documented report on previous conservation treatment [40,41], which is attributable to its ability to identify conservation treatments. Results obtained by Dominguez-Vidal and de la Torre-Lopez [42] on in situ characterization of plasterwork decorations of the Hall of the Kings in the Alhambra (Granada, Spain) with a Raman microspectrometer showed that they consist of different types of pigments. They were identified as cinnaban, minium, carbon black, synthetic ultramarine blue, and natural lapis lazuli. X-ray diffraction determined the nature of a crystalline compound and the structure of natural compounds, too [31]. However, this method is not advocated in all circumstances because of its destructive nature [11].

The 'omics', genomics and proteomics, are innovative molecular-based diagnostic techniques applied in cultural heritage conservation. Genomics gives knowledge of microbes inhabiting a deteriorated heritage and can be used to deduce the active biodeteriogens on the heritage [24,43,44]. The work of Li and Zhang [45] showed the use of this technique to show the array of microorganisms on stone monuments in the vicinity of the UNESCO World Heritage Site at the West Lake Cultural Landscape of Hangzhou. Bacteria, fungi, and cyanobacteria were the potential biodeteriogens discovered.

The use of proteomics before conservation is beneficial because it identifies organic binders used in paintings on a heritage material or in past conservation activities [46]. Even though proteomics has not been used on architectural heritage, it will be useful for the conservation of painted architectural heritage in Nigeria. Mass spectrometer (MS), Fourier Transform Infrared Spectrometer (FTIR), and Sodium Dodecyl Sulphate→Polyacrylamide Gel Electrophoresis (SDS→PAGE) are the tools used for this method. FTIR identifies organic materials and, in some cases, inorganic materials, while SDS→PAGE separates and identifies the particular protein present in the organic material.

1.5. Treatment Interventions

Recent developments in conservation of cultural heritage have resulted in effective, safe, and eco-friendly techniques. These techniques include biotechnology (bioconservation), nanotechnology, and laser technology among others (Figure 4). Clamor for the use of biotechnology in the restoration of cultural heritage started over a decade ago [47,48] and has been applied in developed countries [49,50] but not in Nigeria. The advantages of biorestoration over some traditional methods lies in its non-toxicity to conservators, non-destructive approach, specificity in action, ecofriendliness, and effectiveness [51]. Romano and Abbate [49] demonstrated the safety and effectiveness of using bacteria to remove nitrate salt efflorescence on stone samples. Nitrate and sulphate removal on Matera Cathedral, Italy, by microorganisms was also proved by Alfano and Lustrato [52]. The cloister entrance of San Jeronimo Monastery, Granada, Spain, was damaged by salt weathering and pitting due to environmental pollution. The architectural heritage was consolidated with a set of carbonatogenic bacterial communities [53].

Nanotechnology has been widely applied in heritage conservation as consolidants [54], cleaning agent [26,55], and biocide [56]. Van der Werf and Ditaranto [57] compounded a bioactive zinc (II) oxide (ZnO) nanocomposite for the conservation of the 12th-century church of San Leonardo di Soponto in Italy. The biocide was embedded in a water-repellent consolidant, tetraethyl oxysilane (TEOS), and/ or siloxanes-based material (SILO III and Estel 1100); TEOS, SILO III, and Estel 1100 are nanocomposite materials. SEM-EDS was used to ascertain the geomorphology of the stone monument. It was observed that the nanocomposites consolidated the weathered stone. Cioffi and Torsi [58] developed a copper polymer organo-composite that has antifungal and bacteriostatic properties that were tuned to be released gradually over time.

2. Materials and Methods

The study focused on the perceptions of heritage professionals in using innovative methods in conservation of architectural heritage in Nigeria. Forty heritage professionals participated in a questionnaire survey. Thirty-one (77.5%) questionnaires were dully completed and returned for analysis. The questionnaire was designed into five sections to examine the respondents' level of awareness of the methods (Table 1). The strengths, weaknesses, opportunities, and threats (SWOT) of the methods were also examined through the questionnaire. A Likert scale of 1–4 was employed to determine the level of agreement of the respondents. Cronbach's alpha reliability test value of 0.76 established the validity of the research instrument. Data were analyzed and presented with the use of frequency tables, mean, standard deviations, and rankings to explain the factors influencing implementation of innovative methods in conservation of architectural heritage in Nigeria. The study further examined conservation interventions implemented between 2018 and 2021 at (1) Gidan Madaki (N 7°16′34.96″ E 10°25′7.84″) in Kafin Madaki in Ganjuwa, Local Government Area of Bauchi State, (2) Palace of Deeji of Akure Kingdom (N 7°15′07.3″ E 5°11′37.2″) in Akure South Local Government of Ondo State, and (3) Zaria Friday Mosque (N 9°54′47.88″, E 8°53′5.03″) in Jos North Local Government of Plateau State.

Table 1. Structure of the questionnaire.

Section	Description
A	Elicit demographic characteristics of the respondents such as years of experience, level of education, and employment status
B	Asked questions to determine the level of awareness and use of the innovative methods
C	Focus on the strengths of the methods
D	Asked questions to understand the weakness of the innovative methods
E	Elicit data on the opportunities offered by implementing the innovative methods in the conservation of architectural heritage in Nigeria
F	Collected data on the threats

3. Results

3.1. Demographic Characteristics

Table 2 presents the spread of the respondents based on their level of education, profession, years of experience, and employment status. All the respondents have attained the minimum training of diploma in professions relevant to heritage management and conservation. Architecture (25.81%) and archaeology (19.35%) were the major professions of heritage experts in Nigeria, while 48.39% (n = 15) of the respondents were working in government organizations such as universities, polytechnics, and government ministries.

Table 2. Demographic characteristics of respondents.

Categories	Freq.	%	Categories	Freq.	%
Level of Education			**Years of experience**		
Diploma [1]	4	12.90	Less than 5 years	7	22.58
Bachelor	19	61.29	5–10 years	13	41.94
Masters	5	16.13	10–15 years	5	16.13
Doctorate	3	9.68	15–20 years	6	19.35
Profession			20 years and more	0	0.00
Architecture	8	25.81	**Employment characteristics**		
Archaeology	6	19.35	Works in government organization only [2]	15	48.39
Civil engineering	2	6.45	Works in a private organization only	7	22.58
Computer science	2	6.45	Works for an international organization	3	9.68
Fine art	3	9.68	Works for both government and private organizations	6	19.35
History	4	12.90	Works in government organization only [2]	15	48.39
Urban & Regional planning	2	6.45	Works in a private organization only	7	22.58
Others	4	12.90			

[1] Including Ordinary and Higher National Diploma. [2] Including government ministries, monotechnics, polytechnics, research institutions, and universities.

3.2. Awareness

The level of awareness about the innovative methods was measured based on three indicators (familiarity, technical know-how, and usage). As indicated in Table 3, familiarity with the innovative technologies was somewhat low (mean value of 2.19), which is a result of less than 30% of the respondents learning about any of the technologies during formal training and 41.9% gaining minimal level of technical know-how about the innovative technologies, attending 'on-the-job' workshops and training sessions. Familiarity is a subjective indicator but was defined in this study as having theoretical knowledge about innovative technologies. The low level of technical know-how (1.34) is also considered

an impediment to usage of the innovative technologies in conservation intervention of architectural heritage in Nigeria. Of the respondents, 38.7% (*n* = 12) had participated in implementing the innovative technologies in conservation interventions. This could be due to low level of skilled heritage professionals who are capable of implementing the technologies. More than 80% of the respondents had implemented photography, GIS, 3D modelling, and photogrammetry for documentation, while 58.06% (*n* = 18) had implemented at least one of the innovative methods for treatment intervention.

Table 3. Awareness about the innovative methods for the conservation of architectural heritage.

Variables	Mean [1]	SD [1]	Rank
Familiarity with the innovative technologies	2.19	1.12	1st
Level of technical know-how of the innovative technologies	1.34	0.67	3rd
Usage of innovative technologies	1.58	0.89	2nd

[1] Likert scale of 1–4 (1 for very low, 2 for low, 3 for high, and 4 for very high).

3.3. SWOT Analysis

It is pertinent to understand the perception of respondents to the strengths of implementing innovative technologies for documentation, diagnosis, and treatment of deterioration in architectural heritage in Nigeria. The strengths focus on the positive impacts and attributes of the innovative technologies on the conservation of architectural heritage (Table 4). The respondents strongly agreed that employing innovative technologies in conservation of architectural heritage will improve the performance of conservation intervention (mean value of 3.58), provide new knowledge to heritage professionals (3.62), and enhance the quality and quantity of data available on architectural heritage in Nigeria (3.79). On the other end, there was disagreement that implementing the technologies will engender inter-organization collaboration (1.84) due to the poor state of information sharing and collaboration that is experienced across the non-governmental and governmental organizations within the heritage management sector in Nigeria. The respondents also ranked enhancement of quality and quantity of data on architectural heritage as the most important strength of employing innovative conservation technologies while improvement of collaboration between organizations ranked least.

Table 4. Potential strengths of implementing innovative technologies for the conservation of architectural heritage.

Variables	Mean [1]	SD [1]	Rank
Improves the performance of conservation interventions in architectural heritage	3.58	1.63	3rd
Improves innovation in the conservation of architectural heritage in Nigeria	2.26	1.14	7th
Improves timely completion of conservation interventions	3.05	1.24	5th
Provides new knowledge to heritage professionals in Nigeria	3.62	1.53	2nd
Enhances economic viability of architectural heritage in Nigeria	1.98	1.03	8th
Strengthen knowledge sharing and collaboration across heritage professionals	3.08	1.46	4th
Improves collaboration between government and private organizations	1.84	1.02	9th
Enhances the quality and quantity of data available on architectural heritage in Nigeria	3.79	2.12	1st
Strengthens heritage conservation policies	2.49	1.28	6th

[1] Likert scale of 1–4 (1 for strongly disagree, 2 for disagree, 3 for agree, and 4 for strongly agree).

The results shown in Table 5 reveal the potential weaknesses of employing innovative techniques in the conservation of architectural technologies in Nigeria. The cost of equipment and tools needed for the technologies, adequacy of trained professionals, and availability of funds constitute concerns to the respondents. The weaknesses need to be addressed to ensure realization of the benefits of the innovative technologies in protection of the values and significance of the architectural heritage in Nigeria. The increased cost of conservation intervention (ranked fourth) is also one of the weaknesses that need to be addressed because cost–benefit of implementing the innovative technologies is vital to determining how to conserve the architectural heritage.

Table 5. Potential weakness in implementing innovative technologies.

Variables	Mean [1]	SD [1]	Rank
Inadequate skill capacity of heritage professionals	3.62	1.68	2nd
Poor funding of the heritage management sector in Nigeria	3.54	1.47	3rd
Loss of traditional knowledge of conserving architectural heritage	3.02	1.58	5th
Requires expensive hard- and software	3.69	1.42	1st
Requires varying technical skills	2.75	1.22	6th
Increased cost of conservation intervention	3.45	1.62	4th

[1] Likert scale of 1–4 (1 for strongly disagree, 2 for disagree, 3 for agree, and 4 for strongly agree).

Tables 6 and 8 reveal the opportunities and threats to the implementation of innovative technologies in conservation and protection of architectural heritage in Nigeria, respectively. The results of mean and standard deviation in Table 6 reveal the main opportunity of the innovative technologies is 'protection of values and significance inherent in the architectural heritage' (3.84), while the potential of innovative heritage to encourage young people to study professions relevant to heritage conservation (1.45) is the least ranked opportunity of implementing the innovative technologies. The potential threats, as shown in Table 7, reveal that respondents considered the innovative technologies as threats to the local trades and practices used in conserving the architectural heritage. The respondents also agreed that the production of large amounts of data about the architectural heritage (2.79) could threaten the strengths and opportunities of implementing the innovative technologies in Nigeria.

Table 6. Potential opportunities in implementing innovative technologies.

Variables	Mean [1]	SD [1]	Rank
Protects values and significance of architectural heritage in Nigeria	3.84	1.42	1st
Improves awareness of the communities to architectural heritage in Nigeria	3.21	1.45	3rd
Improves the quality of research on architectural heritage in Nigeria	3.32	1.03	2nd
Influx of young people to study professions relevant to heritage conservation	1.45	0.67	5th
Improves review and monitoring of conservation intervention	2.76	1.25	4th

[1] Likert scale of 1–4 (1 for strongly disagree, 2 for disagree, 3 for agree, and 4 for strongly agree).

Table 7. Potential threats to implementing innovative technologies.

Variables	Mean [1]	SD [1]	Rank
Production of too large an amount of data	2.79	1.32	2nd
Difficulties in collaboration with professionals	1.36	1.09	3rd
Difficulties in combining different techniques	1.14	0.78	4th
Threatens local trades and practices relevant to the conservation of architectural heritage	2.96	1.43	1st

[1] Likert scale of 1–4 (1 for strongly disagree, 2 for disagree, 3 for agree, and 4 for strongly agree).

3.4. Analysis of Conservation Intervention

Three conservation interventions were conducted by the National Commission for Museums and Monuments (NCMM) from 2018 to 2021 using different methods for documentation and treatment of different forms of deterioration and defects. Gidan Madaki, an example of earthen architecture built in 1860, was declared a national monument on 16 February 1956 and remains among the rare architectural heritage of the late Muhammed Durugu, a renowned master builder who designed various Emir palaces in Northern Nigeria. The palace of Deeji of Akure Kingdom, declared as a national monument on 15 February 1989, was built as a symbol of socio-political, economic, and spiritual development of Yorubas after the end of the trans-Atlantic slave trade. The walls, doors, and windows of the palace were embellished with artworks and motifs, while Zaria Friday Mosque was designed and built in 1830 by the master builder Babban Gwani Mikhaila to serve as space for Islamic religious activities. The mosque was declared a national monument in 1970 to serve as a source of knowledge about traditional architecture in Nigeria.

The three national monuments were built using mud bricks (tubali), stones, wood, sandcrete plaster, and local steel. The buildings, however, are threatened by termites, storms, floods, and other climate elements (Figure 6). Therefore, NCMM implemented conservation interventions from 2018 to 2021 to address the extent and impacts of defects threatening the values and safe use of the monuments. Table 8 discusses the processes and methods implemented by NCMM to address the observed deteriorations on the three national monuments. The defects observed on the three monuments were documented using digital photography and physical observation but none of the defects was diagnosed to understand the causes and extents of the defects. The heritage professionals from NCMM addressed the defects through processes for removal, restoration, and reconstruction (see Table 8).
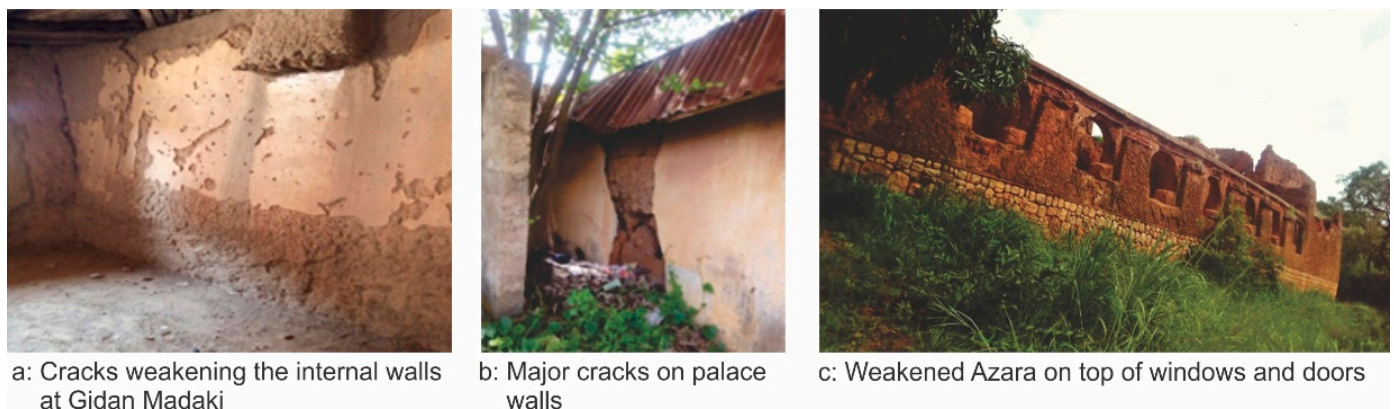

a: Cracks weakening the internal walls at Gidan Madaki

b: Major cracks on palace walls

c: Weakened Azara on top of windows and doors

Figure 6. Observed defects on three national monuments in Nigeria (**a**). cracks weakening the internal walls at Gidan Madaki, (**b**). major cracks on palace walls, and (**c**). weakened Azara on top of windows and doors). Adapted from NCMM [59].

Table 8. Conservation intervention for observed deteriorations in three national monuments in Nigeria.

Heritage Building	Observed Deterioration	Documentation Methods	Diagnosis Methods	Treatment Interventions
Gidan Madaki	Growth of weeds on the surrounding areas, inner courts, and roof	Digital photography, physical observation	Not implemented	- Clearing of weeds and debris - Spraying of herbicides
	Dilapidation and deterioration at Soron Salama, external and internal walls			- Mending deteriorated areas with polythene leather and mixed Makuba
	Damage to the dome and Azara in the roof of Soron Jakadiya			- Construction of new columns - Replacement of the damaged Azara
	Termite attacks on various parts of the building			- Fumigation of the whole building
	Dilapidation of load-bearing columns			- Removal of the dilapidated columns - Erection of new columns
Palace of Deeji of Akure Kingdom	Weed infestation of the courtyards	Digital photography, physical observation	Not implemented	- Removal of weeds - Application of herbicides
	Minor and major cracks on the palace walls and floors			- Mending the cracks with sandcrete mortar
	Blockage of drainages			- Removal of debris from drainages - Construction of new outlets
	Termite attacks in parts of the building			- Fumigation of the whole palace
	Collapse of parts of the floor slabs			- Removal of collapsed parts of floor slabs - Construction of new portions of floor slabs
	Damaged and blown-off roofing sheets at the courtyards			- Replacement of blown-off roof with new and old galvanized zinc sheets
	Deterioration of roof carcass			- Mending of roof leakages with bituminous felts - Replacement of deteriorated roof carcass
	Dilapidation of load-bearing walls in parts of the palace			- Mending the cracks with reinforcement and concrete - Supporting portions of wall with buttresses
Zaria Friday Mosque	Deteriorated portions in the roof	Physical observation, Digital photography	Not implemented	- Removal of deteriorated roof covering and carcass - Installation of new roof covering and carcass
	Weakened Azara on top of windows and doors			- Removal of weakened Azara - Installing new Azara using local materials such as makuba, dunfuna, and rama
	Growth of unwanted plants in parts of the building			- Removal of weeds and other unwanted plants

4. Discussion

The findings of the study revealed that innovative technologies are most applied for documentation of architectural heritage to conduct activities related to surveying, recording, and presentation of data on architectural heritage. The results also show that many of the heritage professionals in Nigeria are government staff and have inadequate skill capacity to implement innovative tools. The findings corroborate Akinkunmi [2], who emphasized the need for improvement of skill capacity of heritage professionals in developing and implementing innovative methods for conservation of architectural heritage to address various forms of deterioration impacting the authenticity and values of the heritage.

Most of the heritage professionals, as well, are familiar with the innovative technologies, mainly through theoretical propositions without hands-on practice of the innovative methods for diagnosis of deterioration in architectural heritage. This is due to poor funding of government organizations with responsibilities of conserving and managing the architectural heritage in Nigeria, inadequate state-of-the-art equipment and facilities, and poor inter-organization collaboration and information sharing. Adetunji and Essien [33] also emphasized the need to review the curriculum in practice in tertiary institutions training heritage professionals to include 'hands-on' workshops and field work to expose the students to various technological innovations in heritage conservation.

In the study conducted by Osasona and Ewemade [60], the values of architectural heritage were embedded in the good and rare quality of craftwork and traditional knowledge that connects the building to histories of the people and positions the building in the identity of the community. This assertion is corroborated by the findings in the high ranking of the opportunity of the innovative technologies to protect the values and significance of the architectural heritage. Omisore and Ikpo [21] also confirm the significant relationship between the age of the building and the rate of conservation needed in architectural heritage in Nigeria.

The findings equally revealed that heritage professionals have concerns about the amount of data that will be produced if innovative technologies were implemented and the performance of conservation interventions. However, Hassani [30] regards the challenges in implementing innovative technologies for the documentation and diagnosis stages of conservation. It is, therefore, vital to develop appropriate policies and strategies for data management, especially for conservation intervention. Gbadegesin and Osaghale [15] emphasized the vital role of heritage management policies in improving the performance of conservation interventions and ensuring data collected during the interventions are used to improve research into various issues affecting heritage conservation in Nigeria.

5. Conclusions

Architectural heritage conservation in Nigeria is not effectively practiced compared to developed countries and it is still rooted in only traditional methods of conservation to the exclusion of innovative techniques. The application and benefits of innovative technologies in architectural heritage conservation cannot be overemphasized. The technologies are effective and could unravel the constituents of heritage materials, identify potential biodeteriogens, safely clean heritage surfaces, and consolidate materials and they are sustainable. Few studies have been conducted on innovative techniques in conservation of cultural heritage in Nigeria, but more studies are needed on the indicators of adopting innovative technologies and the perception of local communities to implementing the techniques in conservation of architectural heritage.

Conservation of values and significance of architectural heritage demands a combination of traditional and innovative methods to maintain the connection of local communities as well as to improve the success of conservation interventions through the implementation of evidence-based innovative techniques. The study, at first, advocates increased awareness through training of professionals involved in conservation on the usefulness of complementing the traditional methods with the innovative methods. Innovators should

also communicate the need for these techniques in such a way as to connect innovation and practicality in the field. Second, the necessary equipment and materials needed to actualize the innovative methods to conservation of architectural heritage should be provided. Funding has been known to be a major challenge in conservation of architectural heritage in Nigeria. Stakeholders should, therefore, source funds to salvage Nigeria's architectural heritage. Based on the findings, employing innovative methods offers vast opportunities and benefits in improving the performance of conservation interventions. No doubt, the innovative methods will also assist heritage professionals to understand the values and significance of the vast architectural techniques and comply with internationally agreed standards for heritage conservation.

References

1. NCMM. Declared and Proposed National Monuments. 2019. Available online: http://ncmm.gov.ng/declared/ (accessed on 3 January 2021).
2. Akinkunmi, O.J. Conservation of traditional earth building in Nigeria: Case study of Origbo in Ife-North, Osun State. *Int. J. Afr. Soc. Cult. Tradit.* **2016**, *4*, 20–31.
3. Kigadye, F.S. Architectural Conservation in Rapidly Urbanising Cities: The Case of Dar es Salaam, Tanzania. *Cah. Afr. Est East Afr. Rev.* **2014**, *49*, 29–54.
4. Leissner, J.; Kilian, R.; Kotova, L.; Jacob, D.; Mikolajewicz, U.; Brostrom, T.; Ashley-Smith, J.; Schellen, H.L.; Martens, M.; van Schijndel, J.; et al. Climate for Culture: Assessing the impact of climate change on the future indoor climate in historic buildings using simulations. *Herit. Sci.* **2015**, *3*, 38. [CrossRef]
5. Sterflinger, K.; Piñar, G. Microbial deterioration of cultural heritage and works of art—Tilting at windmills? *Appl. Microbiol. Biotechnol.* **2013**, *97*, 9637–9646. [CrossRef] [PubMed]
6. Godts, S.; Hayen, R.; De Clercq, H. Investigating salt decay of stone materials related to the environment, a case study in the St. James church in Liège, Belgium. *Stud. Conserv.* **2017**, *62*, 329–342. [CrossRef]
7. ICOMOS. Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage. In Proceedings of the 14th General Assembly, Victoria Falls, Zimbabwe, 27–31 October 2003.
8. Ryal-Net, M.B.; Prugnal-Ogunsote, B.; Ola-Adisa, E.O. Assessment of Selected English Colonial Heritage Features for Sustainable Conservation in Kaduna Metropolis, Nigeria. In *Urban and Architectural Heritage Conservation within Sustainability*; IntechOpen: London, UK, 2019.
9. Gherardi, F.; Gulotta, D.; Goidanich, S.; Colombo, A.; Toniolo, L. On-site monitoring of the performance of innovative treatments for marble conservation in architectural heritage. *Herit. Sci.* **2017**, *5*, 4. [CrossRef]
10. Theodoridou, M.; Török, A. In situ investigation of stone heritage sites for conservation purposes: A case study of the Székesfehérvár Ruin Garden in Hungary. *Prog. Earth Planet. Sci.* **2019**, *6*, 15. [CrossRef]
11. Zhao, C.; Zhang, Y.; Wang, C.-C.; Hou, M.; Li, A. Recent progress in instrumental techniques for architectural heritage materials. *Herit. Sci.* **2019**, *7*, 36. [CrossRef]
12. Kourouma, S.K. The ritual hut of Sosso-Bala in Niagassolo. *Tradit. Conserv. Pract. Afr.* **2005**, 68–73.

13. Urzì, C.; De Leo, F.; Bruno, L.; Krakova, L.; Pangallo, D.; Albertano, P. How to control biodeterioration of cultural heritage: An integrated methodological approach for the diagnosis and treatment of affected monuments. *Works Art Conserv. Sci. Today* **2010**, 1–9.

14. Fais, S.; Casula, G.; Cuccuru, F.; Ligas, P.; Bianchi, M.G. An innovative methodology for the non-destructive diagnosis of architectural elements of ancient historical buildings. *Sci. Rep.* **2018**, *8*, 4334. [CrossRef]

15. Gbadegesin, J.T.; Osaghale, G. Management Challenges of Cultural Property in Nigeria. *Afr. J. Hosp. Tour. Leisure* **2014**, *3*, 1–18.

16. Embaby, M.E. Heritage conservation and architectural education:"An educational methodology for design studios". *HBRC J.* **2014**, *10*, 339–350. [CrossRef]

17. Mohd-Isa, A.; Zainal-Abidin, Z.; Hashim, A. Built heritage maintenance: A Malaysian perspectives. *Proced. Eng.* **2011**, *20*, 213–221. [CrossRef]

18. Sabri, R.; Olagoke, O.A. Predicaments in the Management of Religious Heritage Buildings and Sites in Nigeria. *Conserv. Manag. Archaeol. Sites* **2019**, *21*, 45–65. [CrossRef]

19. Ewemade, F.O.; Osasona, C.O. Upgrading Ile-Ife's vernacular architecture heritage. In *Structural Studies, Repairs and Maintenance of Heritage Architecture*, 11th ed.; WIT Press: Southampton, UK, 2009; pp. 59–70.

20. Eze, C.J.; Obaje, J.A.; Zubaru, S.N. Evaluation of traditional methods in the maintenance of mud houses for environmental sustainability in Northern Nigeria. *J. Archit. Construct.* **2018**, *1*, 34–43.

21. Omisore, E.O.; Ikpo, I.J.; Oseghale, G.E. Maintenance survey of cultural properties in Ile-Ife, Nigeria. *J. Build. Apprais.* **2009**, *4*, 255–268. [CrossRef]

22. Abdulkarim, B.I.; Abdullahi, Y.A.; Salam, K.A. Corrosion resistance of commercial roofing sheets to acid rain water in Eleme rivers, Nigeria. *Intern. J. ChemTech Res.* **2009**, *1*, 802–806.

23. Feilden, B.M. *An Introduction to Conservation of Cultural Property*; ICCROM and UNESCO: Paris, France, 1979; pp. 74–82.

24. Perito, B.; Cavalieri, D. Innovative metagenomic approaches for detection of microbial communities involved in biodeterio-ration of cultural heritage. In Proceedings of the IOP Conference Series: Materials Science and Engineering, Florence, Italy, 16–18 May 2018; IOP Publishing: Bristol, UK, 2018.

25. Moropoulou, A.; Zendri, E.; Ortiz, P.; Delegou, E.T.; Ntoutsi, I.; Balliana, E.; Becerra, J.; Ortiz, R. Scanning Microscopy Techniques as an Assessment Tool of Materials and Interventions for the Protection of Built Cultural Heritage. *Scanning* **2019**, *2019*. [CrossRef]

26. Kapridaki, C.; Verganelaki, A.; Dimitriadou, P.; Maravelaki-Kalaitzaki, P. Conservation of Monuments by a Three-Layered Compatible Treatment of TEOS-Nano-Calcium Oxalate Consolidant and TEOS-PDMS-TiO$_2$ Hydrophobic/Photoactive Hybrid Nanomaterials. *Materials* **2018**, *11*, 684. [CrossRef] [PubMed]

27. ICE. *Report Assessing Innovative Restoration Techniques, Technologies and Materials used in Conservation*; Bláha, J., Novotný, J., Eds.; Institute of Theoretical and Applied Mechanics of the Czech Academy of Sciences: Prague, Czech Republic, 2018.

28. Stylianidis, E.; Remondino, F. *3D Recording, Documentation and Management of Cultural Heritage*; Whittles Publishing Dunbeath: Caithness, UK, 2016.

29. Gulotta, D.; Toniolo, L. Conservation of the Built Heritage: Pilot Site Approach to Design a Sustainable Process. *Heritage* **2019**, *2*, 797–812. [CrossRef]

30. Hassani, F. Documentation of cultural heritage techniques, potentials and constraints. *Intern. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2015**, *40*, 207. [CrossRef]

31. Herrera, L.K.; Le Borgne, S.; Videla, H.A. Modern methods for materials characterization and surface analysis to study the effects of biodeterioration and weathering on buildings of cultural heritage. *Intern. J. Arch. Herit.* **2008**, *3*, 74–91. [CrossRef]

32. Gadd, G.M.; Dyer, T.D. Bioprotection of the built environment and cultural heritage. *Microb. Biotech.* **2017**, *10*, 1152–1156. [CrossRef]

33. Adetunji, O.S.; Essien, C.; Owolabi, O.S. eDIRICA: Digitizing Cultural Heritage for Learning, Creativity, and Inclusiveness. In *EuroMed 2018, LNCS 11196*; Springer: Cham, Switzerland, 2018; pp. 447–456.

34. Okpalanozie, O.E.; Adebusoye, S.A.; Troiano, F.; Polo, A.; Cappitelli, F.; Ilori, M.O. Evaluating the microbiological risk to a contemporary Nigerian painting: Molecular and biodegradative studies. *Intern. Biodeterior. Biodegrad.* **2016**, *114*, 184–192. [CrossRef]

35. Urzı, C.; De Leo, F. Sampling with adhesive tape strips: An easy and rapid method to monitor microbial colonization on monument surfaces. *J. Microbiol. Methods* **2001**, *44*, 1–11. [CrossRef]

36. Pepe, O.; Sannino, L.; Palomba, S.; Anastasio, M.; Blaiotta, G.; Villani, F.; Moschetti, G. Heterotrophic microorganisms in deteriorated medieval wall paintings in southern Italian churches. *Microbiol. Res.* **2010**, *165*, 21–32. [CrossRef] [PubMed]

37. Polo, A.; Gulotta, D.; Santo, N.; Di Benedetto, C.; Fascio, U.; Toniolo, L.; Villa, F.; Cappitelli, F. Importance of subaerial biofilms and airborne microflora in the deterioration of stonework: A molecular study. *Biofouling* **2012**, *28*, 1093–1106. [CrossRef] [PubMed]

38. Ruga, L.; Orlandi, F.; Fornaciari, M. Preventive Conservation of Cultural Heritage: Biodeteriogens Control by Aerobiological Monitoring. *Sensors* **2019**, *19*, 3647. [CrossRef] [PubMed]

39. Proietti, A.; Leccese, F.; Caciotta, M.; Morresi, F.; Santamaria, U.; Malomo, C. A new dusts sensor for cultural heritage applications based on image processing. *Sensors* **2014**, *14*, 9813–9832. [CrossRef]

40. Casadio, F.; Daher, C.; Bellot-Gurlet, L. Raman spectroscopy of cultural heritage materials: Overview of applications and new frontiers in instrumentation, sampling modalities, and data processing. *Anal. Chem. C Herit.* **2017**, 161–211. [CrossRef]

41. Vazquez-Calvo, C.; Martinez-Ramirez, S.; Alvarez de Buergo, M.; Fort, R. The use of portable Raman spectroscopy to identify conservation treatments applied to heritage stone. *Spectrosc. Lett.* **2012**, *45*, 146–150. [CrossRef]

42. Dominguez-Vidal, A.; de la Torre-Lopez, M.J.; Rubio-Domene, R. In situ noninvasive Raman microspectroscopic investigation of polychrome plasterworks in the Alhambra. *Analyst* **2012**, *137*, 5763–5769. [CrossRef] [PubMed]

43. Liu, Z.; Wang, Y.; Pan, X.; Ge, Q.; Ma, Q.; Li, Q.; Fu, T.; Hu, C.; Zhu, X.; Pan, J. Identification of fungal communities associated with the biodeterioration of waterlogged archeological wood in a Han dynasty tomb in China. *Front. Microbiol.* **2017**, *8*, 1633. [CrossRef] [PubMed]

44. Piñar, G.; Dalnodar, D.; Voitl, C.; Reschreiter, H.; Sterflinger, K. Biodeterioration risk threatens the 3100 year old staircase of Hallstatt (Austria): Possible involvement of halophilic microorganisms. *PLOS ONE* **2016**, *11*, e0148279. [CrossRef] [PubMed]

45. Li, Q.; Zhang, B.; Yang, X.; Ge, Q. Deterioration-associated microbiome of stone monuments: Structure, variation, and assembly. *Appl. Environ. Microbiol.* **2018**, *84*, e02680-17. [CrossRef]

46. Rao, H.; Li, B.; Yang, Y.; Ma, Q.; Wang, C. Proteomic identification of organic additives in the mortars of ancient Chinese wooden buildings. *Anal. Methods* **2015**, *7*, 143–149. [CrossRef]

47. Rinaldi, A. Saving a fragile legacy. *EMBO Rep.* **2006**, *7*, 1075–1079. [CrossRef]

48. Fernandes, P. Applied microbiology and biotechnology in the conservation of stone cultural heritage materials. *Appl. Microbiol. Biotech.* **2006**, *73*, 291–296. [CrossRef] [PubMed]

49. Romano, I.; Abbate, M.; Poli, A.; D'Orazio, L. Bio-cleaning of nitrate salt efflorescence on stone samples using extremophilic bacteria. *Sci. Rep.* **2019**, *9*, 1668. [CrossRef] [PubMed]

50. Palla, F. Blue-Biotechnology and Biocleaning of Historic-Artistic Artifacts. *Conserv. Sci. C Herit.* **2017**, *16*, 185–196.

51. Marin, E.; Vaccaro, C.; Leis, M. Biotechnology applied to historic stoneworks conservation: Testing the potential harmfulness of two biological biocides. *Int. J. Conserv. Sci.* **2016**, *7*, 227–238.

52. Alfano, G.; Lustrato, G.; Belli, C.; Zanardini, E.; Cappitelli, F.; Mello, E.; Sorlini, C.; Ranalli, G. The bioremoval of nitrate and sulfate alterations on artistic stonework: The case-study of Matera Cathedral after six years from the treatment. *Intern. Biodeterior. Biodegrad.* **2011**, *65*, 1004–1011. [CrossRef]

53. Jroundi, F.; Schiro, M.; Ruiz-Agudo, E.; Kerstin, E.; Martin-Sanchez, I.; Gonzales-Munoz, M.T.; Rodriguez-Navarro, C. Protection and consolidation of stone heritage by self-inoculation with indigenous carbonatogenic bacterial communities. *Nat. Commun.* **2017**, *8*, 279. [CrossRef]

54. Chelazzi, D.; Poggi, G.; Jaidar, Y.; Toccafondi, N.; Giorgi, R.; Baglioni, P. Hydroxide nanoparticles for cultural heritage: Consolidation and protection of wall paintings and carbonate materials. *J. Colloid Interface Sci.* **2013**, *392*, 42–49. [CrossRef]

55. Giorgi, R.; Ambrosi, M.; Toccafondi, N.; Baglioni, P. Nanoparticles for cultural heritage conservation: Calcium and barium hydroxide nanoparticles for wall painting consolidation. *Chem. A Eur. J.* **2010**, *16*, 9374–9382. [CrossRef]

56. Becerra, J.; Mateo, M.; Ortiz, P.; Nicolas, G.; Zadarenko, A.P. Evaluation of the applicability of nano-biocide treatments on limestones used in cultural heritage. *J. C Herit.* **2019**, *38*, 126–135. [CrossRef]

57. Van der Werf, I.D.; Ditaranto, N.; Picca, R.A.; Sportelli, M.C.; Sabbatini, L. Development of a novel conservation treatment of stone monuments with bioactive nanocomposites. *Herit. Sci.* **2015**, *3*, 29. [CrossRef]

58. Cioffi, N.; Torsi, L.; Ditaranto, N.; Tantillo, G.; Ghibelli, L.; Sabbatini, L.; Bleve-Zacheo, T.; DAlessio, M.; Zambonin, P.G.; Traversa, E. Copper nanoparticle/polymer composites with antifungal and bacteriostatic properties. *Chem. Mat.* **2005**, *17*, 5255–5262. [CrossRef]

59. NCMM. *Reports on Recent Restoration Works Carried out at Gidan Madaki and Palace of Deeji of Akure Kingdom*; National Commission for Museums and Monuments: Abuja, Nigeria, 2011.

60. Osasona, C.; Ewemade, F. Ile Timi: The interface between traditional and vernacular architecture in Ile-Ife. *Struct. Stud. Repairs Maint. Herit. Archit. XII* **2011**, *118*, 99.