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Interaction between microbes and facade materials: A review of biodeterioration of facade materials in Enugu, Southeast, Nigeria.

Isiofia, Lawrence A., Obiefuna, J.N. and Ugwu C.I[b]

Department of Architecture, Enugu State University of Science and Technology (ESUT), Agbani.
[b]Department of Urban and regional planning Enugu State University of Science and Technology

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Corresponding Author's E-mail:
Imbconsultants2@yahoo.com

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ABSTRACT

This paper reviewed the deleterious effects of microorganisms on the façades of buildings in general and Enugu in particular. It defined microbial colonization of facades, explained how it leads to façade failures, the concepts of buildings, building materials and façades, impact of climate on biodegradation of façades and explained the various issues in the interaction.. In doing so it assesses current works on biodeterioration and strategies in Nigeria and beyond with specific impact of their deteriorations on cementitious materials. Included in this review are suggestions on how to broaden the knowledge and understanding the influence of microbes on facade materials to mitigate the impact and highlight some grey areas requiring further inquiries on the discourse.

1.0 Introduction

Microbes are a biological short term for microorganisms. They represent a range of nano-sized and incredibly diverse living organisms that cannot be seen with our naked eyes (Isiofia, 2004). They are unicellular organisms which could be of botanical (Algal and Bacterial), Fungal, zoological (Protozoa and Eukaryotes) and Viral origins. They are inevitably, the pioneer organisms in any development of life, and are ubiquitous in air, water and soil (Bertron, 2014). They have very active reproductive system enabling them to reproduce large numbers of themselves within given seconds thereby spreading through length, breadth and across the surfaces (colonisation) of their hosts objects or medium, materials, say. This ability to reproduce fast and in large numbers makes them to live and survive in clusters of themselves (colonies) on any material they meet. For microbes to survive and reproduce they require food (moisture, dissolved minerals, sunlight and others) from a source which in some cases can be derived from their host materials often times leading to obliteration, deterioration, degradation (failure) of the material's designed function. Building materials, in a general sense, are those materials out of which buildings are constructed and they include materials of mineral, botanical, animal and synthetic origin which in the built environment, are categorized as raw materials, primary materials, composite materials and building elements. Building materials for finishes and facings are all materials for finishing buildings and structures. Finishes are those materials used as as the final covering on every building element for aesthetic, protective or additional structural support. These façade materials, due to biodeterioration, material's composition and use become susceptible to microbial invasion, which in turn led to either failure or defects and have attracted the attention of researchers in the built environment in Nigeria and beyond. In Enugu, Southeast Nigeria, many facades of buildings and monuments were either deteriorating or had deteriorated. In some cases, the materials of the facades are either failing or have failed aesthetically or deformed. Some buildings recently completed are made to look like they were built many years before.

2.0 Literature Review

Isiofia 2021 investigated the microbial colonization of building finishes and facings in Enugu metropolis. His findings revealed that exposed facades of cementicious materials, irrespective of use, are three (3) times more liable to microbial invasion than any other materials for finishes. This is due to their porosity and surface roughness. His results agreed with Kukletová and Buchta, 2018; Guillitte (1995), Saiz-Jimenez (1997), Dubosc Escadeillas and Blanc., (2001), Gaylarde and Gaylarde (2005, 2003), Beltran, (2014) and Grosseau, Dalod, Lors, Guyonnet and Damidot., (2015). Nnaji, Amadi and Molokwu 2016 Studied biodeterioration of external cementitious materials in Nsukka, southeast Nigeria and opined that microbial colonization is a major issue in our immediate environment capable of negative aesthetic, structural and health related problems. In Lagos, southwest, Nigeria, Obidi and Okekunjo (2017) reported that microbially induced discolourations are unsightly feature occurring on painted walls of Lagos, the commercial nerve centre of Nigeria, suggesting that their activities damages the aesthetic functions of the buildings. In same Lagos, Obidi, Aboaba, Makanjuola and Nwachukwu, (2009) also reported that paint material, intended for use were found to have deteriorated due to microbial action resulting in foul smell, viscosity loss, discolouration and visible surface growth with serious economic implications to the paint industry. Negative impacts of microbe – material interaction is not peculiar to tropical environments. In the state of Michigan, United States of America, the city of Detroit has been demolishing 200 vacant houses weekly since 2014, to fight the blight of urban decay (because of biodeterioration) hoping that it will have positive impact on improving the remaining property values (Larson, Xu, Ouellet and Klahm, 2019). Vupputuri, Fathepure, Wilber, Seifollah, Tyler, and Ramsey, (2013) studied several corroding bridge sites in Texas, U.S.A and discovered that microbes were responsible for the corrosion of concrete bridge columns. In Asia, Yoon, Kim, Koh and Pyo 2020, observed that porous cementicious material generally have low density with a high-water absorption capacities. Their research also showed that the water absorption capacities of cementitious materials are inversely proportional to their densities. This porosity may be a conduit for food and sustenance for microbes. Lors (2021) opined that cementitious materials commonly used in the construction of buildings and monuments are subject to ageing depending on their service environments. The host environment is a critical factor in the proliferation of microbes. Ageing of cementicious material creates a bioreceptive surface and with a favourable condition, they develop, grow and colonise the cementitious surface. In most cases, they hyphae penetrate the material's depths to cause degradation. Fungi, cyanobacter and bacteria are implicated here. Ljesevic Gojgic-Cvijovic, Stanimirovic, Beskoski and Brceski, 2019) showed that microbes can grow on surfaces of concrete, pores and micro-cracks, producing varying metabolites. The metabolites, particularly acids, degrade concrete components and affect its deterioration by abiotic factors. Deterioration of concrete is a serious problem worldwide since it affects construction functionality and requires high maintenance costs. It can cause severe damage to concrete sewerage systems, wastewater treatment systems, bridges and piers, offshore platforms, etc. thus severely influencing the economy by raising maintenance costs. Recent studies by (Kukletová and Buchta, 2018; Gaylarde, Ribas, Silva. and Warscheid., 2003) on sandcrete materials suggests that porosity, texture, surface roughness of sandcrete materials, humidity, pH and climate are responsible for its susceptibility to colonization by microbes. For deeper understanding, it is important to look at some of the frameworks on microbes and building materials interactions are considered.

2.1 Concepts of Buildings, Building Materials and Facades

The Collins English dictionary (2021), defined Building as the general term applied to a fixed structure in which people dwell or work. It is any structure intended for shelter, housing or enclosure of persons, animals, or chattels (USLEGAL, 1997-2021). It means any structure that has roof and walls especially a permanent structure. Buildings differ from structures by having a roof over it as a condition. This implies that all buildings are structures but all structures may be buildings (Isiofia, 2021). Buildings can be categorised into two: the sub and superstructure. The superstructure comprise the interior and exteriors. The latter are sometimes called, skin or façade. The exterior building finishes acts as the skin of buildings displaying the architectural characteristics of structures and monuments whilst defining space and shelter of buildings. It defends buildings against, harsh climate and microbial proliferation while still storing energy, heat and water (Sandak, Brzezicki and Kutnar., 2019). In recent times, however, microbes have invaded these façade elements and reducing their aesthetic functions and of course, their rental values, by so doing. The number of façades affected by the growth of microbiological biofilm is currently, increasing. These microbes, are propagated onto the facades through surrounding air, they multiply and produce unsightly coloured coatings, so-called biofilms (Kukletova and Buchta, 2018). Composition of a biofilm depends on climatic conditions and other factors of which humidity is the most important. With the tiny air-borne particles of organic matter propergated, altogether, with air dust, serving as nutrients, colonization sets in. possibility of survival, and extent of colonization depends primarily on the material's surface, building location, sunlight, presence and type of surrounding greenery, pH of the adjacent soil, and last but not least the building use how it is used used.

2.1 Concepts of biodeterioration in microbial colonisation of materials

Biodeterioration describes the processes that have affected humankind in exploiting and utilising materials for construction. Biodeterioration, not to be confused with biodegradation, is any undesirable change in material's property caused by the vital activities of microbes (Huck, 1965; 1968). Alternatively, it is an undesirable change in the material's properties caused by biological agents (Stanaszek, 2020). Relationship existing between biodeterioration and microbial colonization is that in most cases, the later results in biodeterioration of the materials colonized (Isiofia, 2021). In recent decades, concerns have been raised about the deterioration of historic buildings and cementitous materials (Saiz-Jimenez, 1997; Suihko, Alakomi, Gorbushina, Fortune, Marquardt and Saarela, 2007; Magniont, Coutand, Bertron, Cameleyre, Lafforgue, Beaufort and Escadeillas, 2011; Bertron, 2014; Nnaji, Amadi and Molokwu, 2016; Yoon., Kim, Koh and Pyo 2020; Stanaszek, 2020; Isiofia, 2021)

2.2 Impact of Climate on Biodegradation of Facades

Merlin 2012 had suggested that in principle, buildings properly designed, built and maintained should be able to remain undamaged. In practice, it is hardly achievable as the climate hosting the building and age are the critical determining factors. Buildings facades are exposed to microbes in variety of ways which include climatic conditions (temperature, ultraviolet (UV) / solar radiation and moisture), microclimate, air parameters, façade location in relative to the sun (Stanaszzek-Tomal, 2017) and associated agent of denudation, are mainly responsible in degradation and hence occurrence of defects and damages to the external building finishes. These factors not only act individually to cause deterioration but also have a synergistic effect and in coassociation with biological agents in the decay of facade finishes (Aluko et al., 2013).

2.2.1 Temperature

Temperature affects the process of deterioration gradually and in a variety of ways. Changes in temperature induce a thermal gradient between the surface layer and the inner layer of building materials (particularly in materials with low thermal conductivity) and consequently may result in the degradation of the mechanical properties of the material and can lead to formation of cracks. The formation of cracks on materials is accompanied by loss of strength and increase in porosity, which lowers the chemical resistance of the material (Stanaszzek-Tamol, 2017). Temperature fluctuations of building materials can influence bulk expansion, such as the expansion of stone grains, the dilatation of different materials in joints and the expansion of water in material capillaries. Increased ambient air temperature is one of the reasons for the rate of wet deposition being more important for deterioration processes in tropical and subtropical regions. Higher ambient temperature reduces the effects of freeze-thaw cycles. Zara (2015) has shown that temperature affects microbial communities, which agreed with (Morita, 1975).

2.2.2 Solar radiation

This causes temperature variations in materials and can induce volume changes in the material's pores due to expansion of water molecules inherent in the material agitated by the radiation. Solar radiation plays important role in photochemical reactions since it supplies the energy for the excitation or splitting of bonds in the reacting molecules inherent in the material (Muncmanová, 2007).

2.2.3 Moisture

Moisture is one of the primary factors affecting the microbial proliferation (Zare, 2015; Grant, Hunter, Flannigan and Bravery, 1989). Moisture damage has always been an issue in buildings since wet materials can support microbial growth. It accelerates material deterioration (Flannigan and Morey, 1996) and cause health problems for occupants (Dales, Burnett and Zwanenburg, 1991). Moisture and nutrients in materials affect the microbial communities. In every situation where building materials can be in contact with moisture, microbes can colonise them. Interactions between life and materials, in some cases, affect materials service properties, durability, safety of building materials, products and structures (Libert, Schultz, Esnault, Fe´ron and Brillstein, 2014). increasing flooding and rainfall related to climate change is aiding fungi to grow more rapidly, causing degradation of the mechanical and of course, properties of buildings and infrastructure (Kazemian, Kakpour, Milani and Klironomos, 2019; Stanaszzek-Tamol, 2017). In addition, their proliferation puts occupant's health at risk. Gaylarde C.C 2020 stated that humidity level should be considered one of the most important determinants of microbial colonization of buildings. Material's moisture content is expressed as moisture content and water activity (aW). It is defined as the volumetric fraction (m^3/m^3) or mass fraction (kg/kg) of water in the material while a^W is the ratio of vapour pressure of water in a material to the vapor pressure of pure water at the same temperature. The relative humidity (RH) above the surface of a material in an equilibrium condition called equilibrium relative humidity (ERH) which is equivalent to water activity only at equilibrium conditions (Zare 2015). Ayrest, (1969), studied the effect of a^W and temperature on twelve fungi species using culture-based method on the agar medium in glass tubes. The investigation showed that if water activity is low, a higher temperature is needed to activate growth. In most materials, an increase in the RH causes further deterioration due to prolonged wetness time, higher deposition rates of pollutants and better conditions for biodeterioration. Among climatic factors, humidity plays the most significant role in outdoor metal corrosion (Muncmanová, 2007).

2.3 Microbes on Facades of Buildings and structures

All building materials can deteriorate and decay if they are not protected and maintained correctly (Designing Building Wiki, 2021). They suggested natural agents, moisture, shrinkage, exposure conditions, corrosion, loading and chemical agents as the sources of deterioration. Natural agents in this regard include biodeterioration, age, and weather and the nature of the Material. Microbial growth can initiate in buildings if the growth requirements of environmental microorganisms are satisfied. In general, moisture is the critical factor. Thus, the main issue of microbial proliferation focuses around moisture and microbial damage in buildings. The materials of the building facade confer protection on the building against weather conditions. Material's surface water absorption by materials can support growth of microbes (Demo, 2017). All any damp surfaces in a building (concrete, stone, brick, plaster, wood, plastics, painted surfaces or metal) may become colonised by microbial cells settling from the air. The colonizing microbes are bacteria, fungi and some algae and together with the products of their metabolism, such as acids and polymeric materials, they form a biofilm, which can trap particulate materials, thus increasing the disfiguring effect of the biofilm (Gaylarde and Morton, 1999). Colonization by microbes causes aesthetic deterioration of facade materials. This phenomenon depends on geographical situation, environmental conditions and surface state of the substrate (Grosseau, Dalod, Lors, Guyonnet and D'Amico, 2015). The surface state of the substrate when considered in terms of porosity and roughness, In this case, materials with cementitious finish are likely be susceptible to microbial invasion. Cementitious materials are heterogeneous, porous and their surface roughness can vary within a wide range. All these properties define the bioreceptivity of a material (Saiz-Jimenez, 1997, Dubosc, Escadeillas and Blanc, 2001). Grosseau, et al, (2015), opined that cementitious matrices partially weather because of the presence of carbon dioxide in the atmosphere. The natural carbonation of the mineral matrix leads to a decrease in surface pH and favours the microbial colonization (Warscheid, and Braams, 2000; Barberousse, Ruot, Ye´pre´mian and Boulon, 2007), and an alkaline surface pH can inhibit microbial colonization of a material. Following a recent study using X-ray CT (Nikon Metrology XT H 320, Japan) for characterizing porous internal structures of cementitious materials, Yoon, Kim, Koh and Pyo, (2020) observed that porous cementicious material generally have low density with a high-water absorption capacities. Their findings on the charaterisation of pores using binary imaging to evaluate pore ratio, showed that the four samples tested were almost about 30% pores of the overall size. Exposed buildings of cementicious finishes, irrespective of use, are three (3) times more liable to microbial invasion than any other materials for finishes. This is due to their heterogeneous porosity and surface roughness (Isiofia, 2021). Microbes, especially fungi, invade theses surfaces and in so doing, contribute to their decay thereby constituting failure of aesthetic functions and others (Campana, Sabatini and Frangipani 2020). Within the built environment, human behaviour and building design contribute to the accrual and dispersion of microbe (Horve, Lloyd, Mhuireach and Ishaq, 2020; Isiofia, 2021). The built environment is an important habitat for humans. Microorganisms are also important to the outdoor environment and are often different from those found indoors. (Zare, 2015). Building materials, design and climate are all factors co affecting microbial growth. Therefore, it is necessary to explore outdoor microbial communities and their relationship to the built environment. Since environmental conditions and buildings materials play an important role in providing the favourable conditions for growth and proliferation of microorganisms, collaboration of microbiologists with building scientists will provide a wider perspective on the built environment (Kelley and Gilbert, 2013; Zare, 2015). In addition, geographical location and seasons are the most important factors affecting fungi (Zare 2015; Amend, Seifert, Samson and Bruns, 2010). Therefore, there is need for in-situ studies for investigations of outdoor microbial communities simultaneously with building science parameters including temperature, moisture and illumination, geographical location and seasonality. Building materials can be exposed to microbes in almost every aqueous medium or damp environment, water being the indispensable condition for life development. Microbial activities can be responsible for mineralogical, chemical and microstructural damage to the material (biodeterioration). Deleterious effects can also concern the aesthetics of a building (proliferation of coloured biological stains on facades and roofs) or the quality of indoor air (presence of microorganisms in damp buildings). Microbes can also act on structures through their own appearance (Bertron, 2014). Aside aesthetic obliterations, materials can suffer mineralogical and microstructural damage (Giannantonio, Kurth, Kurtis and Sobecky, 2009; Wiktor, Grosseau, Guyonnet, Garcia-Diaz, 2011). Microbial stains lead to significant cleaning costs and to image prejudice in the case of prestigious buildings. Microbes have detrimental effects on the structures and construction materials that compose them in many cases (Leemann, Lothenbach and Hoffmann, 2010). In aggressive aqueous media such as waste waters, ground waters, sea waters, agricultural/agro-industrial environments (Bertron, Coutand, Cameleyre, Escadeillas and Duchesne, 2006), and industrial effluents, structures—often made of concrete—can suffer deterioration linked to the activity of microorganisms (Wang, Cullimore and Chowdhury, 2011). On structures, Microbes act through their metabolic processes producing metabolites, many of which are chemically aggressive to building materials especially concrete (Alexander, and De Belie, 2013). They can also degrade materials through formation of biofilms on their surfaces, which locally generate high concentrations of aggressive metabolites (Magniont, Coutand, Bertron, Cameleyre, Lafforgue, Beaufort and Escadeillas, 2011), or the physical action of hyphae of fungi on the material (Gaylarde and Morton, 1999; Gu, Ford, Berke and Mitchell, 1998). The deterioration of materials such as loss of alkalinity, erosion, sapling of concrete skin, corrosion of rebars and loss of water leads to a significant increase in the direct cost of structural maintenance and indirect costs linked to loss of production income (De Belie, Richardson, Braam, Svennerstedt, Lenehan and Sonck, 2000; Johnson, 2008).

2.4 Concrete and sandcrete

Microbes can grow on surfaces of concrete, pores and microcracks, producing varying metabolites. The metabolites, particularly acids, degrade concrete components and affect its deterioration by abiotic factors (Ljesevic, Gojgic-Cvijovic, Stanimirovic, Beskoski and Brceski., 2019). Biodeterioration of concrete is a global problem affecting construction and involves high maintenance costs. It can cause severe damage to concrete in wastewater treatment/sewer systems, bridges and piers, offshore platforms, etc. thus severely influencing the economy by raising maintenance costs. The degradation manifests through physical and chemical changes such as corrosion, cracking or load fatigue. In addition, the durability of concrete can be influenced negatively. All types of building and ceramic materials, concrete and cement can deteriorate because of microbial action, and in some environments, Fungi dominate the microbiota and play an important role in biodeterioration of concrete (Gu, Ford, Berke and Mitchell., 1998; Nica, Davis, Kirby, Zuo and Roberts., 2000; Zhdanova, Zakharchenko and Vember., 2000 and Scherer, Ortega-Morales and Gaylarde., 2009). Apart from structural uses, cement concrete are used for barriers in all kinds of nuclear waste repositories. Despite their theoretical service life reaching up to one million years, biocorrosion is an important factor to consider over such periods. Microbial attacks on concrete is mediated by protons, organic and inorganic acids and the production of hydrophilic slimes, leading to biophysical/biomechanical deterioration (Scherer, et al., 2009). Fungal degradation may proceed more rapidly than bacterial degradation, with complexation suggested as the main mechanism of calcium mobilization. Microfungi from the genera Aspergillus, Alternaria and Cladosporium were able to colonize samples of the concrete used as radioactive waste barrier in the Chernobyl reactor and leached Iron, Aluminium, Silicon and Calcium, and reprecipitated Silicon and Calcium oxalate in their microenvironment (Fomina, et al., 2007c). Fungi are also important members of the microbial communities (including Lichens) that colonise and cause deterioration of 'normal' concrete and cement used in buildings and other structures. Beltran (2014) opined that Since concrete is the most widely used building material, understanding the interactions between microbes and cementicious materials is crucial and constitutes a fundamental step toward more durable, safer, better quality structures in many contexts. Nevertheless, except for the case of biodeterioration in sewer systems, these phenomena have only recently been considered by building material and product manufacturers, owners, civil engineers and contractors, and research funders. In the scientific literature, it is also quite a recent topic, the coverage of which has been increasing, especially since the late 1990s. Current unanswered questions pertain to both scientific and technical aspects. Among other things, the specific impact of microorganisms on concrete structures in terms of biodeterioration mechanisms—apart from that of their metabolites—is not well understood (Beltran, 2014). Comments from Vupputuri, et al., (2013) suggested that microbially-induced corrosion of concrete is a significant global problem incurring losses in the order of billions of dollars per year. The microbial communities responsible for the deterioration of concrete structures are poorly understood because most of the previous studies were conducted with conventional culture-dependent techniques that could detect only a limited range of microorganisms. A better understanding of the microbial diversity and community structure of corroded concrete is vital to develop new approaches to mitigate microbial corrosion. Recent advances in molecular-based approaches were shown to be very useful in detecting the presence of microbes that cannot be cultivated using standard laboratory techniques. The objective of Bertron (2014) was to apply recent molecular tools to better characterise the microbial population associated with concrete and their dynamics during corrosion process. Ljesevic et al., (2019) studied the influence of microbes on concrete deterioration and detected various bacterial genera in deteriorated concrete and showed that sulphate reducing bacteria (SRB) such as Desulfovibrio, Desulfomaculum, neutrophilic sulphur-oxidising bacteria (NSOB) (Thiobacillus, Thiothrix, Thiomonas, Halothio- bacillus), acidophilic sulphur-oxidising bacteria (ASOB) (Acidithiobacillus), and heterotrophic bacteria (Bacillus, Ochrobactrum, Mycobacterium). Shkromada, Ivchenko, Chivanov, Tsyhanenko, Tsyhanenko, Moskalenko, Kyrchata, Shersheniuk and Litsman, (2021), studied the effect of microbial and chemical corrosion on concrete structures operated in the conditions of chemical enterprises. By investigating the depth and degree of damage to concrete at the microscopic level, using raster electron microscopy, they found out that even when a construction project complied with all building codes, concrete structures eventually undergo chemical and biological corrosion and that it is possible to reliably predict the timing of decommissioning of plants in order to prevent industrial disasters.

2.4.1 Sandcrete

Recent studies by (Kukletová and Buchta, 2018; Gaylarde et al., 2003) on sandcrete materials suggests that porosity, texture, surface roughnes of sandcrete materials, humidity, pH and climate are responsible for its suceptibity to microbial colonization. Nnaji, et al., (2016), investigated the biodeterioration of external cementitious walls in Nsukka, Southeast, Nigeria aimed at finding the factors responsible for the growth and proliferation of microbes on sandcrete walls and its effect. They examined 200 randomly sampled buildings for presence of microbial growths. Characteristics such as texture of the walls, statuses of their rendering, painting, age of building, and nature of soil surface/cover amongst others was logged. The wall's compressive strengths was in-situ determined using rebound hammer. Their results showed that microbes colonised 130 buildings (about 65.3%) out of the 200 hundred buildings. they concluded that microbial colonization is a major issue in our immediate environment that can cause negative aesthetic, structural and health related problems. They observed that most people are neither aware of the negative impacts of microbial colonization on their health nor on the durability of buildings. Instead, they are only aware of the aesthetic failures, which they commonly addressed by scraping off worn out paint and repainting. They ended by suggesting the use of microbial sandcrete technology to increase increase durability of various building materials. Possible mitigative measures suggested by Nnaji et al., (2016) is given in table 1.

Table 1 Particulars and Impacts of Mitigation Options

Types and *method	Materials	Environmental/health impact	*Application interval	*Cost	Nature	Remarks
Mechanical corrective						
Sand blasting	Silica beads sand, steel grits, copper slag, walnut shell and bits of cocoanut shell	Silica beads and sand dust are associated with lungs disease,	Once or twice per year	High	Active	Scars concrete surface
Soda blasting	Sodium bicarbonate	Can affect the pH of soil and water	Once or twice per year	High	Active	*Labour intensive
Dry ice blasting	3 mm ice pellets, CO_2	None	Once or twice per year	Medium	Active	*Labour intensive
Pressure washing	Water propelled at high pressure	Abrasion of concrete surface	Once or twice per year	Medium	Active	* Labour intensive
Chemical preventive						
Biocides	Quaternary ammonium, aldehyde, alcohols, phenolics, organic acids and isothiazolinones	A wide variety of ailments nervous system impairment, lungs damage	Variable	Medium	Passive	*Labour intensive
Chemical preventive						
Photochemical coatings	Titanium dioxide	Increase in ground level ozone due to photochemical breakdown of NH_3; Associated with lungs and heart disease	Once every 5-10 years	Medium	Passive	Requires adequate light for optimal activity. Immobilization by building materials could inhibit activity; can remove odour
Zeolite	Zeolite compounds	No known health effects. Slight inhibition of growth of sensitive plants	Once or twice per year	Medium	Passive	Resists bacterial induced deterioration
Temperature and humidity control	-	None	Continuous	High	Passive	Suitable for indoor environment. Mostly applicable in pipelines and boilers

Source: Nnaji *et al*., (2016)

2.5 *Summary and research gap*

Relevant literature reviewed provided information on the role of climate and microorganisms in the deterioration of building facades, exposing their deleterious effects. Studies on cementicious materials suggests that the most affected parts of buildings are the exposed facades especially, those exposed to weather elements (Nnaji et al., 2016; Isiofia, 2021), Surfaces of concrete, pores and micro-cracks, producing varying metabolites (Ljesevic, Gojgic Cvijovic et al, 2019), concrete structures in sewers and marine engineering, underground engineering and other humid environments (Qiu, et al., 2020). Although the review agrees with Bertron (2014) on the microbially-induced corrosion of concrete, is a significant global problem incurring annual losses in the order of billions of dollars, he noted that current unanswered questions exists in both scientific and technical aspects. Bertron (2014) cautioned that the microbial communities responsible for the deterioration of concrete structures are poorly understood because most of the previous studies were conducted with conventional culture-dependent techniques that could detect only a limited range of microorganisms. This underscores the call for molecular-based approach in detecting the presence of microbes that cannot be cultivated using standard laboratory techniques. Some of the reviews show that microbial colonization of building facades is the main cause of their aesthetical deterioration. Grosseau et al., (2015), suggested that the ageing of facades causes changes on the material's surfaces which, in turn, favour the development of microbial species, particularly, in the places in contact with moisture. Since the host environment and climate play key role in the microbial type and growth there is need to localize investigations on microbial growth on buildings within a geographical space and climatic conditions. This view also agrees with (Zare, 2015, Chang et al., 1995; Amend et al., 2010 and Grosseau et al., 2015). Beltran, (2014), opined that since concrete (cementitious material) is the most widely used building material, understanding the interactions between microbes and cementicious materials is vital for durable, safer, better quality structures in many contexts. Although microbes possess positive effect in the healing of cementitious materials, development of bio-based and production of new eco-material (Naveen and Sirakamasuundan, 2016; Cuzman, Wittig, Royo, Abancéns, Herrera, Anastasi, Sánchez., 2015; Varenyam, Achal1, Abhijit Mukherjee2 Sudhakara Reddy, 2010; Kumari, 2015), their negative effect on materials and structures is of serious global concern and responsible for mineralogical, chemical and microstructural damage to materials (biodeterioration). Microbe–material interactions have been identified as being responsible for the increase in building maintenance cost over the years thereby resulting in significant amount of money, time and resources being spent on maintenance works thereby generating non-routine maintenance (Aluko et al., 2013).

2.5.1 Gap and Conclusion

Whilst biodeterioration studies are developing with introduction of molecular tools for the detection, isolation and characterisation of microbial taxas to solve the problems arising from microbial-material interactions, microbes-facade finshes still remain largely unexplored thus creating a yawning gap. This is because, most of the literatures focused more on the microbial communities of the buildings interiors with moisture damage, indoor health challenges and sick building syndrome, typical outdoor environments remain unexplored (Zare, 2015). Microbial colonisation of building materials and biodeterioration have been linked to environmental conditions of the host material (Saiz-Jimenez, 2001) mainly moisture, temperature, and light, as well as by the chemical nature of the material's substratum. However, these climatic conditions are never same on all locations of the globe (Scheerer et al., 2009). As a consequence, microbes favoured in one climatic condition may not in another. Therefore, rather than risk generalization, this paper is of the view that 1.research on biodeterioration should be locale to host communities, 2. That researches of this nature should not stop at isolation, identification and characterisation, rather it should be furthered with testing antimicrobials on the isolates for their eradication because, in spite of many antimicrobial in the market, building facades are still deteriorated in Enugu, Southeast, Nigeria, 3. Researchers in the built environment should collaborate with biotechnologists using building science parameters to broaden the knowledge on this discourse as suggested in Zare, 2015 and Isiofia, 2021.

Areas for Further Studies

From the review, the following areas should be the focus of future research in the microbe – facade material interactions to provide more insight on the discourse:

Interrogating the functions of eave projections to determine any ratio between the projections and building heights in the protection of facades from climatic actions.

Interrogating the performance standards of existing antimicrobials in use in Enugu metropolis

Determination of any relationship between man, monument and environment in the dynamics of microbial proliferations in the biosphere.

3.0 Study area

The area under review is Enugu urban. Enugu urban is within the Enugu metropolis and forms the capital of Enugu state. It describes Enugu urban referencing all geographical location, climate, and vegetation. It also shows the population distribution together with the infrastructure available in the area.

3.1. Geographical Settings

3.1.1 Location

Enugu lies between latitudes 6° 27'9.60″ N - 7°28'N and longitude 7° 30' 37.20″ – 8°19'E covering 556 KM2 on an elevation of 180m above sea level with a total population of 722, 644 (2006 census). Enugu metropolis comprises three council areas Enugu North, Enugu East and Enugu North and South Local Government Areas. It is bounded in the east by Nkanu LGA, in the West by Udi LGA, in the North by Igbo-Etiti and Isiuzor and in the south by Nkanu West LGA.

3.1.2 Climate and Vegetation

Enugu is located in the tropical rainforest zone with a derived Savanah. It has a tropical savannah climate. The weather is humid. The humidity is at its peak between March and November. The mean daily temperature is 26.7 °C. It has two weather; rainy and dry seasons. It has an average rainfall of 2.000mm (Reifsnyder and Darnhofer, 1989).

3.1.3 *Topography*

Although the name "Enugu" was coined from the Igbo words "Enugwu" meaning "hilltop", it actually emphasizes the nature of topography of the Enugu. The natural landform of Enugu is an interplay of hills and valleys, and the layout took the same form, although the topography flattened out in some areas especially around the metropolis. Despite its name meaning hill top in the Igbo language, Enugu lies at the foot of an escarpment and not a hill. Enugu is located in the Cross River basin and the Benue trough and it has the best developed coal in this area. Precambrian basement rock in this region is overlaid with sediments bearing coal from the Cretaceous and Tertiary age. Coal seams in the Enugu coal district measure between 1 and 2 metres (3.3 and 6.6 ft) in thickness and the reserves have been estimated to be more than 300 million tonnes. (Abuja Geographic Information, 2020).

3.1.4 Physiography and Drainage

The geomorphic feature in the Enugu metropolis runs through north-south trending escarpment. The scarp slope of the escarpment rose sharply to the western side reaching a maximum mean elevation of near 400 m above sea level and continued into the Udi Plateau. The metropolis is drained by Ekulu, Iva, Ogbete and Nyaba (Nyama in some dialect) rivers which rises from near the base of the escarpment and flow towards the east into the Cross River Basin. The study area is well drained on the western side due to geomorphological feature of the area while it is poorly drained in the eastern side due to geomorphologic characteristics of the area. Nnamani and Igwe (2020).

3.1.*5 Geology*

The predominant soil type is gravely-silt. It is mostly reddish in colour and has a high bearing capacity for intense building construction. Enugu shale overlays the Agbani Sandstone/ Awgu shale. It is a lateral equivalent of Nkporo/Owelli formation and one of the oldest deposits of Anambra Basin (Nwajide, 1990). The Shale consists of fissile, grey shale with extra formational clast capped on top by Ironstone with presence of pyrite. The shale is associated with extensive sedimetary deformation structures (Nwajide and Reigers, 1999) and lies in the eastern part of Anambra Basin. Enugu Shale is well exposed along Enugu-Onitsha Express Way by New-Market flyover and along Enugu- Port Harcourt Express Way by Ugwuaji flyover.

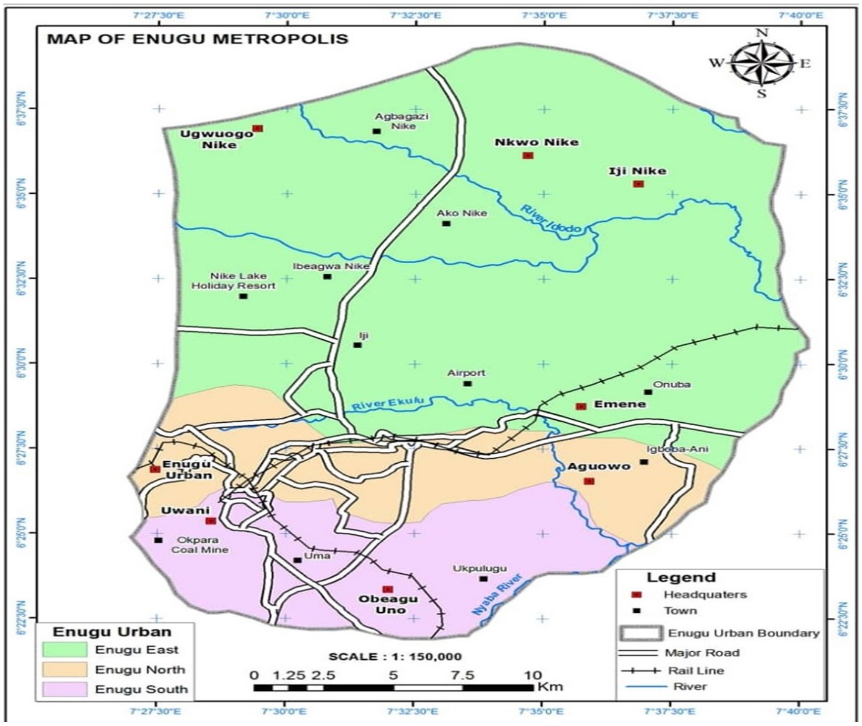

Figure 1 Map of Enugu State showing the 3 L.G.As making-up the metropolis.
Source: Researchgate.Net

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