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Research Article

Construction Materials and Their Influence on Microbial Survival: Implications for Building Hygiene, Indoor Environmental Quality and Public Health

*Osuagwu Andrew Chima [1] and Nnodim Johnkennedy [2]

[1] Department of Building Technology, Federal Polytechnic Nekede, Owerri, Imo State, Nigeria.
[2] Department of Medical Laboratory Science, Imo State University, Owerri, Imo State, Nigeria.

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***Corresponding author: Osuagwu Andrew Chima**
Department of Building Technology, Federal Polytechnic Nekede, Owerri, Imo State, Nigeria.

Abstract

Construction materials play a vital role in influencing the microbiological quality of interior settings. Their physical, chemical and surface qualities influence microbial attachment, survival, proliferation and permanence. Buildings are composed of a variety of materials such as concrete, cement, wood, ceramics, glass, metals, plastics, paints, insulation products and composite materials. These materials have different porosity, moisture uptake, surface roughness, chemical composition and thermal properties, all of which affect their capacity to support or prevent microbial viability. Bacteria, fungus, viruses and other micro-organisms can survive on construction surfaces, particularly if environmental circumstances are favourable, for example the presence of moisture, warmth, nutrients and poor ventilation. Porous materials such as wood, gypsum board and untreated concrete can absorb moisture and organic pollutants providing an environment conducive to microbial development, particularly fungal colonisation. Conversely, non-porous materials such as stainless steel, glass and certain polymeric surfaces may allow microbial persistence, but not necessarily considerable microbial proliferation. Further means of minimising microbial contamination in buildings have been provided by the development of antimicrobial construction materials, such as copper-based surfaces, silver-containing coatings, photocatalytic materials and antimicrobial paints. However, the efficiency is dependent on climatic circumstances, surface features, microbial species and the durability of the material. This review considers the primary categories of construction materials and their effect on microbial survival, adhesion, growth and persistence. It also examines mechanisms of microbial-material interactions, factors affecting microbial survival, antimicrobial construction technologies, implications for healthcare and residential environments, and emerging research prospects. Understanding the connection between construction materials and microbial survival is crucial for selecting appropriate building materials, enhancing indoor hygiene, preventing microbial contamination, and creating healthier built environments.

Keywords: *Building hygiene, bacteria, biofilms, construction materials, environmental microbiology, fungi, indoor environmental quality, microbial survival, public health, antimicrobial surfaces.*

Introduction

The construction materials provide the physical basis of buildings, and have a significant impact on the durability and structure performance, thermal properties, aesthetics and environmental sustainability. In addition to these traditional duties, construction materials are also significant in defining indoor environmental quality and microbiological characteristics of occupied areas. Their surface qualities, chemical composition, moisture retention capacity and interaction with external variables may affect the survival and proliferation of microorganisms within buildings [1].

Microbes are everywhere in the built environment. They infiltrate buildings via external air, human activities, water systems, animals, contaminated materials and ventilation systems [2]. Once introduced, microbes can colonise the surfaces of building and may survive for varied durations or develop colonies under suitable climatic circumstances. The

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common microbiological groups present in indoor environments are bacteria, fungus, viruses and actinomycetes. Some are benign environmental organisms others can produce infections, allergic responses, respiratory problems and material decay [3].

Microorganisms depend on a number of interlinked parameters such as surface porosity, roughness, hydrophobicity, availability of moisture, temperature, availability of nutrients and exposure to sunlight for survival on construction materials. For example, wet timber structures and gypsum boards may encourage fungal development, while metallic and glass surfaces may allow microbial persistence depending on humidity, temperature and contamination levels [4]. The COVID-19 pandemic has highlighted the role of construction materials in microbiological survival, since much attention has been given to the survival of respiratory viruses on commonly touched surfaces. Inhalation of infectious aerosols is a key route of transmission for respiratory pathogens, although contaminated surfaces can also contribute to exposure under specific circumstances [5].

Similarly, construction materials are needed for healthcare facilities, labs, schools and residential structures that ensure efficient cleaning, prevent moisture build-up and reduce microbiological contamination. So, material selection is becoming more and more crucial for infection prevention and building hygiene [6].

This review discusses the relationship between building materials and microbial survival, with an emphasis on the underlying biological mechanisms, properties of different building materials, antimicrobial technology and the impact on public health.

Microbial Interaction Mechanisms with Building Materials

Microorganisms interact with building materials by attaching, adhering, colonising, forming biofilms and, when conditions are favourable, multiplying. These processes depend on the features of the microbes and the physicochemical qualities of the materials.

Microbial attachment is the first step of the interaction of microbes with construction surfaces. Electrostatic interactions, hydrophobic interactions, van der Waals forces and particular chemical interactions involving surface features of the microbe can lead to the attachment of bacteria and fungus. Bacterial cell walls, capsules, pili and extracellular polymeric compounds affect the capacity of bacteria to cling to various surfaces. Fungal spores may adhere to rough or porous objects because of physical trapping and interaction with surface moisture.

Surface roughness is an essential factor since imperfections might provide protected niches where germs are less accessible to cleaning and disinfection procedures [7].

Biofilm production is an important survival strategy for some bacterial and fungal species. Upon attachment, microbes can create extracellular polymeric compounds, including polysaccharides, proteins, extracellular DNA and other biological constituents. These compounds produce a protective matrix that enables microbial aggregation and adherence to surfaces. Biofilms can form on water pipes, concrete structures, plastic surfaces, drainage systems and other building components exposed to moisture.

Microorganisms associated with biofilms may exhibit enhanced tolerance to environmental stress and disinfectants compared to free-living organisms. This is especially true in healthcare settings where polluted water systems and damp surfaces can act as reservoirs of opportunistic pathogens [8].

Microbial survival is the property of microorganisms to remain viable under environmental conditions. Persistence refers to the length of time they remain on surfaces, either by surviving from the initial contamination or by being recontaminated again and over. Bacterial spores, fungal spores, and even non-spore-forming microorganisms have processes that increase their resistance to the environment. Viruses also differ in their stability in the environment, based on their structural features, particularly whether or not they have lipid envelopes.

The length of time that microbes may survive is dependent on environmental parameters like humidity, temperature, UV exposure and surface chemistry. Therefore, different construction materials may promote distinct patterns of microbial persistence [9].

Effect of Different Materials of Construction on Survival of Microorganisms

Different building materials vary greatly in their ability to retain moisture, to accumulate organic matter, and to promote the attachment of microbes. It is crucial to understand these differences to be able to select materials suitable for diverse building situations.

Concrete and cement-based materials are commonly utilised in building foundations, walls, floors, ceilings and structural elements. Their surfaces are microscopically uneven and porous and may retain water and environmental pollutants. Moisture absorption and microbiological adhesion are affected by porosity of concrete. When concrete surfaces are

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constantly wet, have organic deposits and are at the appropriate temperatures, fungal growth, bacterial colonisation and biofilm development can occur.

The high pH of freshly mixed cement may be inhibitory to some micro-organisms because of its alkalinity. These qualities can be altered by carbonation, ageing, surface contamination and environmental exposure. Moisture can be trapped in cracks and broken concrete, offering protective microenvironments for microbial colonisation. Microbial biofilms can grow on concrete surfaces in structures that contain water, such as drainage canals and reservoirs. Using proper sealants, protective coatings, and moisture-control techniques can limit microbial colonisation and improve the lifetime of concrete structures [10].

Roofing, flooring, doors, furniture, wall panelling and decorative architectural features are all typically made of wood. Its natural makeup is cellulose, hemicellulose and lignin, which affect its moisture absorption and its susceptibility to biological degradation.

Wood is also hygroscopic, which means that it will absorb and give out moisture, depending upon the conditions of its environment. Fungal colonisation and wood-decaying organisms are favoured by excessive wetness. Moulds, including Aspergillus, Penicillium and Cladosporium, can grow on damp wood surfaces. Certain fungus secretes enzymes that digest the structural components of the wood leading to discolouration, degradation and diminished mechanical strength.

The sensitivity of the microbes depends on the type of wood, its surface treatment, moisture content and environmental exposure. Proper drying, protective coatings, ventilation and suitable timber treatment can limit fungal growth. Untreated wood can sustain microbial growth when moist, although some research indicate that some wood species may lower the recoverability of some bacteria compared to non-porous surfaces. So, wood should not immediately be considered more microbiologically harmful than all other materials [11].

Ceramic tiles are commonly used in bathrooms, kitchens, hospitals, laboratories and other settings where surfaces need to be cleaned frequently. Glazed ceramic surfaces are usually less porous and have relatively smooth finishes, hence they are less likely to hold moisture and organic impurities than untreated porous materials. However, ceramic surfaces can still harbour bacteria, especially in the presence of organic substances, dampness and when not properly cleaned.

Tile joints and grout may offer additional sites for microbial growth as they are generally more porous than the glazed tile surface. Persistent moisture in the grout might stimulate fungus development and bacterial colonisation. Therefore, in high standards of hygiene conditions, it is vital to utilise non-porous tiles, moisture resistant grout and effective cleaning procedures [12].

Glass is commonly utilised in windows, doors, dividers, labs, and architectural facades. The surface is smooth and nonporous, which is normally good for cleaning and restricts the retention of moisture within the material itself. However, germs can adhere to glass surfaces by physical and chemical interactions. Bacteria and viruses can live on tainted glass, depending on the climatic circumstances, the type of surface contamination and the microbiological features.
Glass does not normally promote microbial proliferation but deposited organic materials may enable microbial survival. It is smooth and resistant to many cleaning chemicals, which makes it helpful in laboratories and health care settings [13].

Metals are often employed in structural parts, door handles, handrails, laboratory equipment, plumbing systems and building surfaces that are touched frequently. Stainless steel is favoured for its durability, corrosion resistance and simplicity of cleaning. However, when contaminated, it may encourage the persistence of bacteria and viruses, especially under favourable humidity and temperature circumstances.

Copper and some copper alloys have antibacterial characteristics. Copper ions can cause damage to microbial cell membranes, proteins and nucleic acids leading to cellular damage and loss of viability. It has been shown that compounds containing copper have activity against a number of bacterial species and certain viruses. Their inclusion into commonly handled surfaces could provide extra germ control in hospitals and public places. However, the antibacterial efficacy depends on the copper content, surface condition, contact length and humidity and the individual microbe involved [14].

Plastics are used for plumbing, flooring, insulation, wall panels, electrical fittings and interior finishes. Common building polymers are the polyvinyl chloride, polyethylene, polypropylene and polystyrene. Many polymeric materials are relatively non-porous and moisture resistant. However, microbial adhesion can develop on their surfaces especially in the presence of organic pollutants and moisture.

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Plastic plumbing systems can contribute to the creation of biofilms, particularly where water is stagnant or disinfectant concentration is insufficient. Biofilms in building water systems can harbour opportunistic bacteria such as Legionella pneumophila and Pseudomonas aeruginosa.

Polymer surface hydrophobicity, chemical composition and ageing properties affect microbial adherence. Scratches and surface deterioration might potentially increase chances for microbial accumulation [15].

Gypsum boards are extensively used for ceilings, walls and interior partitions. They are porous and have paper facings that may contain moisture and organics. Gypsum boards can promote fungal colonisation when exposed to water leaks, flooding or prolonged condensation. Growth of mould can be found on the paper front and can extend into adjacent construction components.

Fungal spores and other biological pollutants can be present in moist gypsum board. Surface cleaning may not be enough to remove microbial growth from within the material, and heavily polluted objects often need to be removed or properly remediated. These concerns can be mitigated by using moisture-resistant gypsum products and proper maintenance of the building [16].

Insulation materials such as mineral wool, fibreglass, cellulose insulation and polyurethane foam are used to manage indoor temperatures and increase building energy efficiency. Their microbiological qualities rely on composition, moisture absorption, surface treatment and quality of installation. Some insulating materials are not easily colonised by microbes yet the accumulation of dust and prolonged moisture levels can lead to fungal colonisation. Bad installation might also cause hidden regions of condensation build-up. Thus, appropriate vapour barriers, moisture management and ventilation are crucial to prevent microbiological contamination within insulated building structures [17].

Factors Influencing the Survival of Microbes on Construction Materials

The capacity of microorganisms to survive in construction materials is affected by the interaction of material qualities and ambient circumstances. The fate of microorganisms on building surfaces—their death, viability, or multiplication—depends on a number of circumstances.

Porosity refers to the presence of tiny holes or pores in a material. Highly porous materials can absorb water, retain organic particles, and provide sheltered places for microbial adhesion. Under the right conditions fungi can grow on such materials as untreated wood, plasterboard, concrete and certain insulation products which retain moisture. In contrast, comparatively non-porous materials such as glass, glazed ceramics, and stainless steel often facilitate easier surface cleaning. But non-porous materials do not necessarily mean that microbes can't survive. Viruses and bacteria may remain alive on smooth surfaces even when microbial development is limited [18].

One of the most important factors controlling microbial growth on construction materials is the availability of moisture. Water is necessary for microbial metabolism, transfer of nutrients, cellular function, and reproduction. Water activity is a measure of water available for biological processes, not the overall moisture content of a material. distinct bacteria have distinct needs for water activity. Fungi are often more tolerant to low water availability than many bacteria, which explains why mould can grow on moist construction materials under situations when widespread bacterial growth is not possible.

Thus, microbial colonisation may be fostered by persistent wetness due to plumbing leakage, condensation, flooding and poor ventilation [19]. Surface roughness might increase microbial adhesion as imperfections can give physical protection from environmental disturbances and cleaning.

Rough surfaces possess small depressions which may trap bacteria. These sites may shield from disinfectant exposure and promote biofilm formation. Smooth, well-finished materials are often easier to clean, especially in hospital facilities where they must be disinfected on a regular basis. The bioreceptivity, or vulnerability to microbial colonisation, of construction materials is affected by their chemical makeup. Sources of nutrients for microbial development may be found in organic materials such as cellulose, starches, and other carbon compounds. Accumulation of dust, skin particles, food leftovers and other organic deposits may further boost nutrient availability. Inorganic materials such as glass and metals generally offer few nutrients but microbes can nevertheless colonise them by consuming organic substances from the environment.

The pH of construction material also affects microorganism survival. The very alkaline cement surfaces may prohibit some organisms while neutral or gently acidic surfaces may sustain a larger diversity of microbial species. Temperature affects microbial metabolism, enzyme activity, reproduction and cell stability. Most indoor environmental microbes have preferred temperature ranges for growth, however some species may endure quite harsh circumstances. Relative humidity affects the amount of moisture on surfaces and the formation of condensation. The constant high humidity increases the moisture content of porous materials and thus favours mould growth and bacterial colonisation. The combined effects of temperature and humidity are thus key drivers of microbial persistence within structures.

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Ultraviolet radiation, especially UV-C, can damage the genetic material of the microbes and so interfere with replication. Natural sunshine also contains UV radiation, although the amount that reaches indoor surfaces depends on the window glass, building orientation and exposure. Surfaces exposed to direct sunlight may have increased microbial inactivation compared to shaded surfaces under otherwise similar conditions. However, exposure to sunshine should not be the replacement for cleaning, disinfection or enough ventilation [20].

Major Microorganisms Associated with Building Materials

Construction materials may contain micro-organisms of public health concern, as well as environmental species which contribute to deterioration of materials. Some types of bacteria can live on building surfaces and in building water systems. These include Staphylococcus aureus, Pseudomonas aeruginosa, Escherichia coli, Bacillus species and Legionella pneumophila.

Staphylococcus aureus can spread on surfaces that people often contact, such as door knobs, furniture and worktops. Some strains are fairly environmentally persistent. Pseudomonas aeruginosa is especially linked with wet environments, plumbing systems and biofilms. It is significant in the prevention of healthcare linked infections because of its persistence in water-containing systems. Water systems, cooling towers, showers and other installations where water temperatures and stagnation conditions encourage the multiplication of bacteria may be a source of proliferation of Legionella pneumophila. Exposure may occur by inhalation of polluted water aerosols [21].

Fungi are among the most common micro-organisms associated with moist building materials. Important genera include Aspergillus, Penicillium, Cladosporium, Alternaria and Stachybotrys. They produce spores that can become airborne when infected construction materials are disrupted. Some fungal species produce allergies, irritants and mycotoxins, depending upon species and environmental conditions. Exposure might lead to allergic responses, asthma aggravation and other respiratory health concerns. Fungal colonisation also causes deterioration of materials by enzymatic destruction of organic building components. Viruses cannot independently reproduce on construction materials as they require living host cells to replicate. Nevertheless, infected building surfaces may act as transient reservoirs from which infectious virus particles might be transferred to hands or other surfaces.

The longevity of viruses depends on their structural properties, environmental circumstances and surface chemistry. Some viruses, such as influenza viruses and coronaviruses, are enveloped in lipids and may be susceptible to environmental conditions and some disinfectants. Certain environmental factors may favour the increased resistance of non-enveloped viruses. The stability of SARS-CoV-2 on experimental surfaces indicated that material qualities and environmental variables affect viral survival. However, surface-mediated transmission is generally regarded to be less crucial than inhalation for Covid-19 transfer. Actinomycetes are filamentous bacteria that are typically found in dirt, dust and organic materials. Some species may be found in wet buildings and contribute to the creation of airborne spores and other biological particles. Their presence may suggest environmental contamination, especially in structures that have been damaged by water. Algae and lichens can colonise external building materials such as stone, concrete and brickwork, especially where there is moisture and sunlight [22].

Antimicrobial Building Materials and New Technologies

The development of antimicrobial construction materials is a key step forward in building hygiene and environmental microbiology. The materials are intended to prevent the attachment of microbes, decrease the vitality of microbes, or stop the formation of biofilms. Copper and copper alloys have shown antibacterial action against a range of bacterial species and several viruses. Copper ions can cause damage to microbial membranes, interfere with the function of proteins and cause oxidative stress. These impacts can lead to cell malfunction and death of the microbe. Copper on door handles, handrails, counters and other regularly handled surfaces can offer added protection in healthcare and public facilities.

However, routine cleaning and disinfection should not be replaced by copper surfaces [23] Silver nanoparticles and silver-containing coatings are increasingly studied for inclusion in construction goods. Silver ions can interact with microbial proteins, membranes and nucleic acids, disrupting important biological processes. Silver coatings have been used into paints, plastics, tiles and other surface materials. Despite their antibacterial potential, questions have been raised about long-term effectiveness, environmental discharge, toxicity and the potential for microbes to evolve or develop resistance to silver-based treatments. Titanium dioxide (TiO 2) is a photocatalytic substance that, when activated by appropriate light, can create reactive oxygen species.

Reactive chemicals can harm microbial membranes, proteins and genetic material. Coatings of TiO 2 have been studied for the covering of glass, ceramics, cement and external construction surfaces. Possible uses include self-cleaning surfaces and decreasing microbiological contamination. However, photocatalytic efficacy is dependent on light intensity, coating characteristics, ambient conditions and the microorganism being targeted.

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Laboratory studies have shown that zinc oxide nanoparticles have antibacterial and antifungal activities. The antibacterial activity of these could include formation of reactive oxygen species, release of zinc ions and destruction of microbial membrane integrity. Zinc oxide has been studied as an ingredient for paints, cement composites, ceramic coatings, and polymeric construction materials.

Further research is needed to confirm long-term durability, environmental safety and effectiveness in real building circumstances. Antibacterial paints might include silver, copper or zinc compounds or other antibacterial ingredients. They are designed to minimise microbiological contamination of walls, ceilings and other building surfaces. Protective coatings can also help to limit moisture penetration, surface deterioration, and the buildup of organic pollutants. However, an antibacterial label does not always mean the product will be clinically effective. Such items need to be independently tested under realistic environmental conditions before they can be recommended for infection prevention [24].

Microbial Degradation of Construction Materials

Some microorganisms thrive on building materials and even take an active part in their degradation. This process, called biodeterioration, is the result of biological activities that change the physical, chemical and mechanical qualities of building components. Fungi are responsible for the decay of timber, plasterboard, wall papers and other cellulose-containing materials. Their extracellular enzymes tear down organic structural components, causing discolouration, weakening and eventual material breakdown. Wood-decaying fungi may induce brown rot, white rot and soft rot depending on the organism and structural components involved. Certain microorganisms cause deterioration of concrete through metabolic processes. For example, reduced sulphur compounds can be converted to sulphuric acid by sulphur-oxidising bacteria. This acid affects cementitious materials leading to surface degradation and structural weakness. This mechanism is very significant in sewage systems, wastewater infrastructure and other humid environments [13].

External walls, roofs, stone buildings and concrete surfaces can be colonised by algae, cyanobacteria, lichens and bacteria. They can grow and lead to staining, discolouration and changes in surface chemistry. Some organisms emit organic acids that help to break down mineral-based construction materials. These processes indicate that microbial contamination is not just a public health issue but also a major problem in structural maintenance and building economics [16].

Microbial contamination of building materials has substantial implications for indoor environmental quality and human health. Fungi can grow on damp building materials and send spores into the air. Exposure to these biological particles may lead to allergic rhinitis, asthma exacerbation and hypersensitivity reactions. People with a compromised immune system are especially susceptible to infection by opportunistic fungus such as species of Aspergillus [8]. In hospital settings, contaminated surfaces can be a route of transmission of healthcare-associated bacteria via direct touch and indirect transfer. Choose the right materials and regularly clean surfaces that are handled often, such as bed rails, door handles, worktops and equipment. The use of robust, non-porous and disinfection friendly materials may improve environmental hygiene and limit the persistence of bacteria. Microbial development on moist construction materials may lead to the discharge of spores, microbial fragments, allergens and other biological particles into indoor air. Renovation, destruction and cleanup of contaminated materials might enhance the emission of these particles. Thus, adequate moisture control, ventilation and building maintenance are vital to preserving acceptable indoor environmental quality [3].

Workers in construction, building maintenance, cleaning and environmental remediation may be exposed to moulds, bacteria and other biological contaminants in the workplace. Proper personal protective equipment, safe material handling, proper ventilation and good remediation methods are critical for decreasing occupational exposure [7].

Implications on Building Design and Construction in Nigeria

The association between construction materials and microbial survival is of particular importance in tropical nations like Nigeria where the high temperature, seasonal rains and generally high humidity may provide optimal circumstances for microbial development.

Persistent moisture in many Nigerian structures is caused by water leaks, poor drainage, low ventilation and poor maintenance of buildings. These conditions can foster the growth of fungus on timber, ceiling plasterboards and other moisture sensitive materials.

So, building experts should consider microbiological features when selecting construction materials.
Some key proposals include:

1. Proper material selection: Choose materials with appropriate moisture resistance, durability and surface properties, particularly in hospitals, laboratories, schools and residential structures.
2. Moisture management: Provide efficient roofing, drainage, waterproofing and plumbing systems to avoid water ingress and constant dampness.

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3. Surface finishing: Choose smooth, durable and easily cleanable surfaces for workplaces that need high levels of hygiene.
4. Timber protection: Use properly seasoned and adequately treated wood to prevent susceptibility to decay by fungi.
5. Antimicrobial materials: Consider well-proven copper-based surfaces and antimicrobial coatings for high-contact settings.
6. Building maintenance: do regular inspections to check for fungal contamination, water leakage, damaged coatings and degrading building materials.
7. Ventilation: Use effective natural or mechanical ventilation to minimise condensation and the accumulation of moisture.
8. Environmental monitoring: Perform frequent microbiological examinations of selected building surfaces and indoor air, especially in healthcare and educational facilities.
   These methods can improve the durability of the building, reduce microbial contamination and promote healthier interior environments [23].

Conclusion

Microbial survival, adhesion, colonisation and proliferation in the built environment are strongly influenced by construction materials. Their physical, chemical and biological properties affect the persistence of germs on building surfaces and their contribution to indoor microbial contamination. Untreated wood, gypsum boards and some concrete products are porous and moisture-retaining materials that may allow microbial development under suitable environmental circumstances. By contrast, relatively smooth and non-porous materials such as glass, glazed ceramics and stainless steel often lend themselves to simpler cleaning but they can nevertheless support microbial persistence.

Emerging antimicrobial construction materials include copper-based surfaces, silver-containing coatings, titanium dioxide, and zinc oxide composites, which have great potential for improving building cleanliness. However, these methods require further research for durability, environmental safety and effectiveness in real-world situations. In Nigeria and other tropical nations, the selection of building materials, moisture control, ventilation and regular maintenance of the building are particularly crucial in preventing microbiological infection.

Ultimately, the integration of microbiological information into construction material selection and building design will contribute to healthier indoor environments, greater durability of structures, less microbial exposure and better public health outcomes.

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