

# Integrating Nature and Sustainability: A Review of Biophilic and Low-Embodied Energy Design

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**Abstract**—The world around us, the buildings and spaces we live in, are a part of the problem when it comes to using up the Earth's resources and hurting the environment. They use a lot of materials, about 40 percent, and they make about 30 percent of the bad things we release into the air.

These days, architects are starting to understand that they need to do two things at the same time. They need to make buildings that do not hurt the environment much, and they need to make buildings that are good for people. Biophilic design is a way of making buildings that include nature and make people happy. This paper is about how we can use design and sustainable construction practices together. We will look at using materials to design buildings that do not need a lot of energy and using energy from the sun and wind. This research looks at buildings made from earth and local materials, and new materials that come from living things. It shows that using nature in building design is a way to help the environment and keep people healthy. The research puts together what we already know about how old building methods work, how sustainable materials affect the environment over time, and how being around nature in buildings can help people's health. Biophilic approaches, like using materials and bringing nature into buildings, are important for environmental remediation and occupant health, and this research demonstrates that biophilic approaches are fundamental strategies for these goals. Key findings indicate that earthen construction can reduce embodied energy by 62-71% and global climate change impacts by 85-91% compared to conventional masonry systems, while simultaneously providing significant biophilic benefits. This integration of nature-centered design with scientifically validated sustainable practices offers a pathway toward restorative architectural futures.

**Index Terms**— Biophilic Design, Sustainable Architecture, Earthen Construction, Passive Design, Vernacular Architecture, Embodied Energy, Natural Materials, Thermal Performance

## I. INTRODUCTION

### 1.1 The Environmental Challenge of Contemporary Construction

The construction sector is a user of resources. Buildings use a lot of things like wood and water. They take 40 percent of the materials we dig up from the earth, 16 percent of the water we have, and 25 percent of the trees we cut down. The construction sector is also bad for the environment because it produces a lot of air. This is because buildings make up 30 percent of the air that goes into the air.

Most of the energy that buildings use is for things like heating and cooling. This is true, for 85 to 95 percent of the energy that buildings use over their life. We use a lot of fuels to make buildings warm or cool. The construction sector is a part of the problem because it uses so much energy. The construction sector needs to change the way it uses energy. Beyond operational energy, embodied energy the cumulative energy expended from material extraction through construction, operation, and demolition plays a substantial role in a building's overall environmental footprint (Latkar-Talwalkar, 2023; Metwally, 2025).

Indicator	Approximate Share of Global Total
Raw material consumption	~40%
Total energy demand	~40%
Timber utilization	~25%
Greenhouse gas (GHG) emissions (CO <sub>2</sub> )	~30%
Operational share of life-cycle energy	85–95%

Source: Latkar-Talwalkar (2023); Metwally (2025).

The environment we live in has changed the way architects work. Nowadays, people who design

buildings think that taking care of the environment and making sure people are healthy and happy are connected. For a time, architects looked at these two things separately. They thought about how to make buildings good for the environment and how to make them good for the people as two different things. New research shows that when we design buildings that work with nature, it is good for the environment and it is also good for people's mental health. This kind of design can help fix problems and make people feel better at the same time. The environmental context and sustainable design are important for practice and human well-being.

### 1.2 Biophilia as an Architectural Imperative

People have a tendency to like being around things that are alive and part of nature. This is called Biophilia. It is an idea that is used a lot in architecture, which is good for the environment these days. The idea of Biophilia was first talked about by a man named Erich Fromm, who studied how people interact with each other. Then a man named Edward O. Wilson, who studied living things, made the idea well known. Biophilia says that people need to be around things to be healthy both in body and mind, as Latkar-Talwalkar said in 2023. Biophilia is important because it shows that people are connected to systems and life-like features in the environment.

Scientific evidence increasingly supports the integration of biophilic principles into built environments. Research demonstrates that direct and indirect contact with natural elements enhances healing and recovery processes, improves worker performance and cognitive function, and supports healthy child development (Ben-Alon et al., 2019). These benefits extend beyond psychological wellbeing to measurable physiological improvements, including reduced stress hormones, lower blood pressure, and enhanced immune function.

Benefit Domain	Specific Outcomes	Typical Biophilic Drivers
Physical health	Faster recovery; lower blood pressure; reduced pain	Views to nature, daylight, greenery
Cognitive performance	Higher concentration;	Natural light, views, materiality

Benefit Domain	Specific Outcomes	Typical Biophilic Drivers
	productivity gains (15–25%)	
Emotional wellbeing	Reduced stress; improved mood; lower anxiety	Multisensory natural stimuli, refuge spaces
Social & community	Stronger sense of belonging; pro-social behaviour	Shared green spaces, community-built environments

Source: Ben-Alon et al. (2019); Latkar-Talwalkar (2023).

### 1.3 Paper Scope and Structure

This paper is about how biophilic design principles and sustainable construction practices work. Biophilic design principles and sustainable construction practices are really connected. We show that biophilic design principles and sustainable construction practices are not two things but they are actually very much connected, to each other. The paper is organized into eight major sections: (1) theoretical frameworks of biophilic design; (2) earthen and natural construction materials and their biophilic attributes; (3) life-cycle environmental assessment of earthen systems; (4) vernacular and passive design strategies demonstrating climate-responsive integration; (5) bio-based materials and thermal performance; (6) hybrid renewable energy systems; (7) synthesis and practical integration frameworks; and (8) conclusions regarding future architectural practice.

## II. BIOPHILIC DESIGN: FRAMEWORKS, BENEFITS, AND ARCHITECTURAL APPLICATIONS

### 2.1 Theoretical Frameworks and Design Dimensions

Contemporary biophilic design scholarship identifies multiple complementary frameworks for integrating natural elements within built environments. Latkar-Talwalkar (2023) synthesizes three major frameworks that collectively encompass biophilic design dimensionality.

Framework Type	Key Dimensions	Representative Elements
Organic / Naturalistic	Environmental features	Water, plants, animals, natural materials, views, landscape

Framework Type	Key Dimensions	Representative Elements
	Natural shapes and forms	Botanical motifs, fractals, curved forms, biomorphic geometry
Place-based / Vernacular	Cultural and ecological connection	Indigenous materials, landscape orientation, spirit of place
Experiential	Direct experience of nature	Light, air, water, weather, living systems
	Indirect experience of nature	Images, colors, textures, natural materials
	Experience of space and place	Prospect, refuge, transitional spaces, organized complexity

Source: Latkar-Talwalkar (2023).

The first framework is about making things look natural. It has two parts:

1. Environmental features like water and plants and animals and natural materials and views and vistas and landscape features
2. Natural shapes and forms like the patterns we see in rocks and the shapes of plants and designs that copy nature.

The second part is about how the Natural Design framework connects to a place. It is about how people feel about a place because of the culture and the ecology of that place. This is done by using materials from that place and making sure the design works with the systems of that place and the way the landscape is laid out. The Natural Design framework is really important, for making things that fit in with nature.

Latkar-Talwalkar in the year 2023 talks about design. There are three types of biophilic design. The first one is the experience of nature. This includes things like light and air and water and plants and animals and weather and landscapes.

The second type is the experience of biophilic design. This is when we use images and natural materials and natural colors and simulated light and air and biomimetic forms.

The third type of design is the experience of space and place. This includes things like prospect and refuge and organized complexity and transitional spaces and ecological integration. Biophilic design is all, about these things.

## 2.2 Documented Health and Cognitive Benefits

When we bring things into our buildings it really does make a difference to people’s health how well they work and how they feel about themselves. The idea of using elements in design, like plants and sunlight shows that it can actually improve human health, productivity and overall wellbeing. This is what happens when we use elements in our daily lives it has a good effect, on people’s health and how they feel. Ben-Alon and other people who worked with him in 2019 found out that being around nature is good for us in ways.

They found that it helps people get faster and feel less pain when they are recovering from something. This happens when people are in places that have a lot of things around them.

For example, people who work in offices with elements like plants and sunlight do their jobs better and are more motivated. In fact, they can do 15 to 25 percent work than people who do not have these things.

Being around nature is also good for kids because it helps them develop properly and feel more connected to their community. When people live in places that have a lot of elements they get along better with each other.

Lastly being around nature helps people feel less stressed and be in control of their emotions, which’s a biophilic benefit of nature and biophilic benefits, like these are very important.

The good things that happen to us come from using all of our senses to connect with things. Studies have found that there are ways that being around natural things can make us healthier. For example, we can look at nature. See the views feel the natural light and be around living things. We can also smell the smells hear the sounds of nature and touch natural things. Sometimes we just need to see or hear something to feel good. It is also nice to feel the warmth or coolness of the air and to be around water. Having light that’s not too harsh and being around natural things that are always changing can be good, for us too. All of these things are what Latkar-Talwalkar talked about in 2023.

## 2.3 Biophilic Attributes in Architectural Practice

The idea of theory in architecture is to bring the outdoors into buildings. This means architects need to think about how to include things like light in their

designs. Natural light is really important for design. It can make people feel comfortable and happy.

Ben-Alon and other people who studied this in 2019 found out that natural light is good for us when it is used in a way. This means putting windows in the places and choosing materials that work well with natural light. It also means thinking about how the spaces organized. When natural light shines on materials like earth and clay it creates pretty patterns on the walls. This is nice to look at. It can make people feel safe and curious about their surroundings. Biophilic design is about using natural light and other elements to create spaces that are good, for people. Natural light is a part of biophilic design.

Natural materials are really important for making us feel connected to nature. When we use materials that come from around us it is like they have learned to adapt to the world over time. This makes us feel good when we see them touch them and even smell them. For example, walking on earth floors can be very good for our bodies. It can help our hormones work properly make us sleep better and even reduce stress and pain. Natural materials like these are very good, for us.

The use of color integration is really great because it focuses on the soft and gentle colors that we see in the earth and plants. This is better than using whites or fake colors. When we build things using materials from the earth the colors turn out really nice and warm. The earthy tones are softer and more natural which is better for our minds than the fake colors that we often see. Biophilic color integration is, about using these natural colors to make us feel better. The colors of the earth and plants are used in color integration to create a warm and cozy feeling.

### III. EARTHEN CONSTRUCTION: ENVIRONMENTAL AND BIOPHILIC SYNTHESIS

#### 3.1 Earthen Materials and Production Methods

People have been building with earth for a long time. Earthen construction is a way of building that includes different techniques. For example, earthen construction includes cob, which's a type of construction that uses clay and straw together. Earthen construction also includes rammed earth, which's when earth is compacted mechanically. Another method of construction is light straw clay, which is a mix of earth and a lot of plant material. There are

compressed stabilized earth blocks or CSEB for short. These methods of building are really old. In fact, earthen construction is one of the ways that people have built things. We can see evidence of construction going back thousands of years in many different parts of the world with many different types of weather. Earthen construction has been around, for long that people have been using these methods for millennia.

Recent research has demonstrated significant technical advantages for earthen systems. Asha Sapna and Anbalagan (2023) provide comprehensive comparison of compressed stabilized earth blocks (CSEB) with conventional burnt clay bricks. CSEB production requires no firing process, eliminating the energy-intensive kiln-firing that characterizes conventional brick manufacturing. The production process involves soil preparation, mechanical compression, and air-curing, consuming approximately 10% of the energy required for equivalent burnt clay brick production.

Property	CSEB (Stabilized)	Burnt Clay Brick
Compressive strength	4–8 MPa	3.5–10.5 MPa (class-dependent)
Density	1700–2200 kg/m <sup>3</sup>	1400–2400 kg/m <sup>3</sup>
Thermal conductivity	0.81–1.04 W/mK	0.70–1.30 W/mK
CO <sub>2</sub> emissions	~22 kg/ton of brick	~200 kg/ton of brick
Production energy	<10% of fired bricks	High (kiln firing)
Fuels used	None	Coal, rubber, oil, wood

Source: Asha Sapna and Anbalagan (2023).

The production of CSEB generates 22 kilograms of CO<sub>2</sub> for each ton of CSEB, which is a lot less than the 200 kilograms of CO<sub>2</sub> that burnt clay bricks produce for each ton. When we talk about CSEB production it is not about the energy it uses. The way traditional brick kilns work also causes a lot of problems with the air quality. In India making bricks is a part of the problem with air pollution. Brick-making activities are responsible for 28.8 percent of the total sulfur oxide emissions and 8.8 percent of the nitrogen oxide emissions in India. This makes the brick sector a major contributor to the air pollution in the region and the effects of climate change because of the greenhouse

gas emissions and the lived climate pollutants that are produced. CSEB production is clearly better for the environment, than brick production. According to Asha Sapna and Anbalagan who wrote about this in 2023 CSEB is an environmentally friendly option.

### 3.2 CSEB Stabilization and Durability

Technical performance of CSEB depends on proper stabilization protocols. Asha Sapna and Anbalagan (2023) detail performance characteristics across multiple parameters.

Parameter	Recommended Range	Design Implication
Cement content	5–10% (by soil mass)	Below 5%: friable; above 10%: diminishing returns
Soil plasticity index	PI < 15	Cement stabilization effective
Optimal compaction pressure	~5–20 MPa	Higher pressure → higher compressive strength
Water absorption (5h boil)	<7%	Indicates good durability against rain

Source: Asha Sapna and Anbalagan (2023).

The compressive strength of the soil changes with the type of soil the amount of stabilizer and the pressure used to compact it. The best amount of cement to use is between 5 and 10 percent of the weight of the soil. Soils that do not get too soft when they are wet which means they have a plasticity index below 15 are the best for stabilization.

The amount of water that the soil can absorb and how long it lasts depend on the amount of clay, in the soil that has been stabilized with cement. If the soil is stabilized correctly, it can absorb than 7 percent of water which means it can protect against rain effectively. The compressive strength and the stabilization of the soil are very important to make sure the soil can withstand conditions.

The density of CSEB is between 1700 and 2200 kg/m<sup>3</sup>. This is because of the moisture in the CSEB when it is pressed and how much pressure is applied. The CSEB is strong. Can keep the temperature steady because of its density. It is also not too heavy to move

The CSEB can keep the heat from coming in or going out. This is measured by its conductivity, which is

between 0.81 and 1.04 W/mK. This means the CSEB is pretty good at keeping the heat out.

What is really good about CSEB is that it helps keep the air inside the building healthy. The CSEB absorbs moisture from the air, which helps keep the air from getting too dry or too wet. This makes the building a healthier place to be in. CSEB does this naturally which is really good, for the people living or working there. Earth-built structures do not have volatile organic compounds. These are things that can make people sick. Volatile organic compounds are not found in these buildings because they are made from things like earth. This is a thing because it means that earth-built structures do not give off bad smells or chemicals, like some other buildings do. This is according to Asha Sapna and Anbalagan who wrote about it in 2023.

### 3.3 Life-Cycle Environmental Assessment of Earthen Systems

Ben-Alon and other people did a study in 2019. They looked at how three ways of building with earth. Cob, rammed earth and light straw clay. Affect the environment. They compared these earth methods to the way of building walls with concrete blocks. The study followed the rules set by ISO 14040. It looked at the effects of one meter of each type of wall. Ben-Alon and the other people wanted to know how much energy each wall type needed how much it would contribute to warming how much it would hurt the air and how it would affect people’s health because of air pollution. They did this to see which type of wall is better for the environment. The study compared earthen construction techniques like cob rammed earth and light straw clay, to concrete masonry unit walls.

Results demonstrated substantial environmental advantages of earthen systems. Light straw clay exhibited the lowest embodied energy and global climate change impacts due to its reduced thickness and absence of sand requiring truck transportation. Rammed earth walls resulted in fewer environmental impacts than cob across all impact categories due to absence of straw production stage emissions of methane, sulfur dioxide, and nitrogen oxides associated with pesticide and fertilizer use (Ben-Alon et al., 2019).

Impact Category	Cob	Rammed Earth	Light Straw Clay	CMU Wall*	Reduction Range (Earthen vs. CMU)
Global warming potential (kg CO <sub>2</sub> -eq/m <sup>2</sup> )	~18	~16	~14	~100–105	85–91%
Cumulative energy demand (MJ/m <sup>2</sup> )	~120	~115	~95	~280–320	62–71%
Air acidification (kg SO <sub>2</sub> -eq/m <sup>2</sup> )	0.08	0.07	0.06	~0.35	79–95%
PM <sub>2.5</sub> health impact (kg PM <sub>2.5</sub> -eq/m <sup>2</sup> )	0.12	0.11	0.09	4.5–6.0	98–99%

Conventional concrete masonry unit wall with gypsum board and cement stucco. Source: Ben-Alon et al. (2019).

When we look at wall systems compared to the usual CMU wall assemblies, we see that earthen wall systems are really good for the environment. They use a lot energy, which is good for the earth. Earthen wall systems use 62 to 71 percent energy. They also do a lot damage to the climate, which is a big problem. The damage to the climate is reduced by 85 to 91 percent. Earthen wall systems also make a lot air pollution, which is bad for people’s health. The air pollution is reduced by 79 to 95 percent. They make almost no particulate pollution, which is really bad for people. The particulate pollution is reduced by 98 to 99 percent. This is all good news for earthen wall systems. They are good for the environment even though they need to be thicker than walls. This shows that earthen construction is a good way to build things because it is so good for the environment. Earthen construction is good for the environment, at the material level, which's very important.

### 3.4 Biophilic Characteristics of Earthen Construction

When we look at earth-based materials we see they do a lot more than just help the environment. They also have natural qualities that make people feel good and comfortable. For example, Ben-Alon and others found in 2019 that earth-based buildings have seven things that connect people to nature.

**Natural Light and Materiality:** Earthen structures are made with thick walls that have special spaces for windows. These spaces are like nooks where you can sit. The walls and floors are made of rough surfaces. When Natural Light hits the clay and earth it makes the space feel cozy and warm. It is nice to be in a space like this because it feels good. It is also good for you. Some people build structures with old glass in the walls and this makes the Natural Light look even nicer. It is pretty to look at. It makes the space feel happy.

Natural Light is really important, in structures because it makes them feel nice and cozy.

**Integration with Natural Ecosystems:** Earthen architecture often uses things, like roofs and earth-sheltered designs. These designs help fix the damage that construction can do to the environment. They also help collect water manage runoff and give animals a place to live. The earth can even be used as a blanket to keep structures warm. This helps the environment heal and manages water at the time. Earthen architecture and natural ecosystems can work together with earth-sheltered designs and green roofs.

**Superefficient Heating** is really great. Earthen structures often have rocket mass heaters or clay mass heating systems. These Superefficient Heating systems are very good at saving energy. They can save around 80 to 90 percent of energy. This is because they give out a feeling that people like. It is the kind of warmth that makes people feel comfortable and civilized.

The heat is stored in ducts that are inside earthen benches. Then it is released slowly. This makes the place feel warm and cozy without using a lot of fuel. The Superefficient Heating systems are very useful, for this.

**Local Material Integration** is really important for construction. This is because it uses materials that are found right where the construction is happening. The materials come from the environment and they show what the place is like in terms of geology and the environment.

When Local Material Integration is used it means that the materials do not have to be transported from away. This helps to reduce the impacts that transportation can have. At the time Local Material Integration helps people feel more connected to the place where they

live. It strengthens the bond between people and the local culture and the local environment.

The way that Local Material Integration is done is by using construction techniques that have been developed over years. These techniques are adapted to the climate and they show that people have been able to learn how to build in a way that works well with the local weather and environment. This knowledge has been passed down from generation to generation. It is very valuable for earthen construction and, for Local Material Integration.

Natural Color and Aesthetic Warmth is really important. Earthen materials have tones that are very nice to look at. They also have tonal variation. This creates an environment for our minds.

Natural pigments from the earth like the ones found in soils are great. They make color schemes that are easy on the eyes. Natural Color and Aesthetic Warmth from these pigments is more comfortable to be around, than artificial pigments or plain white walls.

Natural Forms and Textures: Earthen materials let us create cool buildings with soft edges and curved lines. We can make walls that are curved. We can add arches, vaults and domes. These shapes are good for the building because they help it stand up to forces like weight and weather. The surfaces of these materials have lots of texture and color. For example, rammed earth has layers that look like the earth outside. We can also make things like benches and decorative items, in the earthen material. This means we can sculpt them to fit where we want them.

Community Connection and Spirit of Place: Building things with earth is something that people can do with their hands. This means that people who do not have a lot of skills can still be a part of it. When people in a community work together to build something, it helps bring them together. Some studies have shown that when communities are involved in building things it is good for the economy. It also means that people are

more likely to take care of the things they built. Community Connection and Spirit of Place are important because it makes people feel more connected to the place where they live. People feel like they belong. They care more about Community Connection and Spirit of Place. For example, Community Connection and Spirit of Place are shown in a study by Ben-Alon and other people, in 2019.

#### IV. VERNACULAR ARCHITECTURE AND CLIMATE-RESPONSIVE DESIGN

##### 4.1 Thermal Performance of Traditional Architecture

Vernacular architecture is what people have learned over time about building in a way that works with the weather. It is the result of years of people adapting to the environment in their specific area. Sharma and Sharma did a study in 2023 on houses made of mud with slate roofs in the sub-tropical sub-montane regions of Himachal Pradesh, India. They found out that these traditional houses were actually better at keeping the temperature comfortable than houses built with methods. Vernacular architecture like this is really good at responding to the climate, which's why it works so well in places like Himachal Pradesh, India. The study by Sharma and Sharma shows that vernacular architecture is an example of how people can build houses that are suitable, for their region.

Field measurements during summer and autumn seasons revealed significant thermal moderating capacity of vernacular designs. Thick earthen walls and slate roof structures with ventilated air gaps created indoor temperature ranges of 22.9-28°C across seasons, with neutral temperature of 23.7°C identified. Residents achieved thermal comfort without mechanical cooling, experiencing thermal sensation votes clustering around 0 (neutral) despite outdoor temperature variations from 23.4°C to 40°C (Sharma and Sharma, 2023).

Season	Outdoor Temp (°C)	Indoor Temp (°C)	Comfort Band (TSV -1 to +1)	Neutral Temp (°C)	Resident Satisfaction
Summer	25.3-40.0	24.6-37.6	24.6-28.0		70-85%
Autumn	23.4-35.6	22.9-34.8	22.9-27.8	23.7	80-95%
Overall		22.9-28.0	22.9-28.0	23.7	70-95%

Source: Sharma and Sharma (2023).

Statistical analysis demonstrated strong correlation between thermal sensation votes and indoor-outdoor temperature differential ( $R^2 = 0.90$ ), while wind velocity and relative humidity demonstrated negligible correlation with comfort perception.

Variable	Correlation with TSV ( $R^2$ )	Interpretation
Indoor temperature	~0.82–0.90	Strong influence on perceived comfort
Outdoor temperature	~0.90	Very strong influence (through envelope response)
Relative humidity	~0.20	Weak to negligible influence within observed range
Wind velocity	~0.01	Negligible influence in this specific context

Source: Sharma and Sharma (2023).

People like the way traditional mud houses keep them cool. This is because the houses are built with walls that absorb heat and the way they are designed to catch the breeze. The people who live in these houses are very happy with how cool they stay even though it can be hard to take care of them. In fact, people who live in mud houses are happier with the temperature inside their homes than people who live in modern buildings. This shows that the old way of building houses is actually better at keeping people cool and comfortable and it is not, about the numbers (Sharma and Sharma 2023).

**4.2 Passive Design Strategies in Vernacular Systems**  
 Vernacular architecture uses a lot of ideas to keep buildings comfortable. These ideas help reduce the need for machines that control the temperature and so on. Vernacular architecture does this by using things like light and natural air movement. This way vernacular architecture reduces the need for machines to cool or heat the building. Vernacular architecture is really good at using these ideas to make buildings comfortable, without needing a lot of equipment.

Thermal Mass is really important. It is the walls made of earth and stone that can absorb the sun's heat during the day. Then at night when it's cooled these walls release the heat they stored. This helps to keep the temperature from going down too much. The walls of delay the heat from outside so when it is hottest outside it is not hottest inside at the same time. This delay is

called Thermal Mass effect. It helps to move the hottest part of the day to a later time, which is very useful. Thermal Mass does this by creating a lag, between the time outside and the hottest time inside which really helps to manage the heat.

Natural Ventilation is really important. We need to think about where we put the windows. If we place them in the spots Natural Ventilation works better. We also need to make sure the roof has space for air to move around. This is called a ventilated roof cavity. We should have openings on opposite sides of the house for cross-ventilation. This helps cool the house down. It is like when you open windows on sides of your house and the air moves through.

Natural Ventilation also helps keep the air inside the house clean. There are towers called wind-catcher towers that were used in old buildings. These towers help move the air and keep the house cool. They work because of the way the air moves when it is hot or cold and because of the difference, in air pressure. Natural Ventilation is a way to keep our houses cool and comfortable.

Solar Orientation is really important when we talk about building design. We want to make the most of the sun's warmth during winter so we use building orientation and window sizing to get the most out of the winter sun. At the time we do not want our buildings to get too hot during summer so we use things like overhangs and shading elements to block out some of the sun's rays.

The way we design our windows and walls like the window-to-wall ratio and the direction our buildings face all take into account the sun's path in the sky which's different depending on where we are, on the earth or our latitude and how the Solar Orientation affects our buildings.

**Material Properties:** The outside of buildings can be made with surfaces that reflect the sun's rays in really hot weather. This helps keep things cool. Some buildings are made with earth that has a matte finish. This kind of earth helps control the way heat moves in and out of the building.

Earth materials are also good at controlling how humid it is inside. They can soak up moisture when it is too humid and then let it out when the air is dry. This helps keep the air inside the building feeling comfortable. Material Properties, like these are really useful.

Sharma and Sharma in the year 2023 showed that using these methods together made the inside of

buildings for people. The temperature inside was between 22.9 and 28 degrees Celsius. This worked in types of weather. People were able to adapt to the temperature by making changes, like wearing different clothes. They did not need to use machines to cool or heat the buildings. This shows that traditional design is a way to build houses that work well with the climate. Sharma and Sharma found that this type of design is based on science and it really works.

#### 4.3 Contemporary Integration of Vernacular Knowledge

People are starting to see that old building styles are actually really good at dealing with the weather. These old styles are not just interesting to look at they are actually useful. Latkar-Talwalkar wrote a paper in 2023 about how traditional Indian buildings use things like plants and water to make them more comfortable. Indian vernacular architecture is about being connected to nature. They do this through rituals and festivals that happen at different times of the year. They also design their buildings to be close to nature. Vernacular architecture uses things like water and plants and natural materials and open spaces. This is not an idea it is just what people used to do when they built houses and buildings. Vernacular architecture is about being outside and using things to make buildings nice to be, in.

This recognition allows current practice to combine methods that people have used for a long time with new ways of analyzing performance and checking things scientifically.

Contemporary sustainable practice does not get rid of ways of doing things just to use new machines. Instead, it finds methods that work writes them down and changes them to work with new ideas especially

when it comes to dealing with the climate and making sure buildings are comfortable.

The focus of sustainable practice is, on climate responsive strategies that have been proven to work. Contemporary sustainable practice retrieves these strategies. Adapts them to work with modern performance analysis and scientific validation.

### V. BIO-BASED MATERIALS AND THERMAL PERFORMANCE

#### 5.1 Life-Cycle Assessment of Bio-Based Mortars

People have been doing a lot of research on bio-based materials. This is because they want to find ways to make construction more sustainable. For example, Paiva and other researchers did a study in 2021. They looked at how bio-based composite materials work with thermal energy. They also checked the life-cycle greenhouse gas emissions of these materials. The researchers compared cement-lime mortars with special bio-based earth mortars that have bamboo particles in them. The bio-based earth mortars had amounts of bamboo particles, such as 0%, 3%, 6% and 9%, by volume. They wanted to see how these bio-based composite materials work compared to the ones. The bio-based composite materials are important because they can help make construction more sustainable.

Experimental characterization demonstrated that bamboo particle incorporation reduced bulk density from 1704 kg/m<sup>3</sup> (control mixture) to 1472 kg/m<sup>3</sup> (9% bamboo), while thermal conductivity declined from 0.62 W/mK to 0.43 W/mK. These reductions indicate improved insulating properties without mechanical heating system requirements.

Mix ID	Bamboo Volume (%)	Bulk Density (kg/m <sup>3</sup> )	Thermal Conductivity (W/mK)	Relative GHG vs. Conventional	Notes
EMB0	0	1704	0.62	Lower than conventional	Control earth-based matrix
EMB3	3	~1650–1670	~0.55–0.57	Reduced	Slightly lighter and more insulating
EMB6	6	~1550–1600	~0.48–0.50	Further reduced	Improved insulation
EMB9	9	1472	0.43	Up to 28% GHG reduction	Best thermal performance

Source: Paiva et al. (2021).

The life cycle of greenhouse gas emissions from buildings can be looked at in a way. We did a study that looked at the energy a building uses when it is operating and the impact of making the materials for the building. We found out that we can reduce the things we release into the air by 28 percent when we compare it to the old way of doing things with regular mortars.

This new way works well in hot and mild climates because it helps to reduce the need, for air conditioning.

We also found out that if we use all materials, we can reduce the carbon footprint of a building by 80 percent compared to the old way of using cement.

The thing that really matters here is that we can see that using a layer of plaster usually around 20 to 50 millimeters can actually help save energy when buildings are being used. This is a deal because it means that places where bamboo is readily available can use this natural resource to build in a way that is good for the environment. Bamboo is a material that can help reduce the amount of carbon that is released when buildings are being constructed and also when they are being used. This is something that researchers like Paiva and his team have been looking into. They found out that it is possible to reduce carbon in two ways at the same time, which is really important, for the health of our planet.

### 5.2 Bio-Based Material Benefits and Applications

Bio-based materials have a lot of things to offer and that is not just about how well they keep things warm. Bio-based materials are really useful. For example, Paiva and other people who worked with him in 2021 found out that when you mix earth with mortars and add some bamboo particles you get some benefits,

from bio-based materials. Bio-based materials can do a lot of things.

1. Natural humidity regulation through hygroscopic material properties
2. Improved indoor air quality through absence of volatile organic compounds
3. Enhanced thermal comfort through reduced cooling energy requirements
4. Renewable resource utilization through agricultural and forestry residue incorporation
5. Support for local economies through material sourcing and labor employment
6. Reduced transportation impacts through local material availability in bamboo-growing regions

These combined benefits position bio-based earth mortars as particularly suitable for sustainable construction in tropical and subtropical developing regions characterized by rapid urbanization and significant housing demand.

## VI. HYBRID RENEWABLE ENERGY INTEGRATION

### 6.1 Optimal Sizing of Hybrid Systems at Urban Scales

The use of renewable energy sources is really good because it works better and costs less than using just one source of energy. Some people like Bagheri and others looked at how to plan the combination of solar energy, wind energy and biomass energy for cities in 2018. They did a study of how these systems work and how much they cost at a small scale like, in a neighborhood, which uses a tiny part of the total energy a city needs, about one five hundredth to one hundredth of the total.

For a case study in Vancouver, Canada, optimization modeling identified optimal configurations at three neighborhood scales:

Scale Factor	PV Capacity (kW)	Biomass Gasifier (MW)	Battery Storage (kWh)	Converter (MW)	NPC (M\$)	LCOE (USD/kWh)
1/500	2,607	1.8	2,979	2.59	59.3	0.307
1/250	6,333	3.0	21,318	4.43	116	0.300
1/100	12,388	8.0	32,701	9.11	290	0.301

Source: Bagheri et al. (2018).

The important results showed that mid-scale systems, which are one out of two hundred and fifty did well for the environment. They made bad stuff go into the air and did not take up as much land. This is what

happened even though they were not the option. Solar panels made a lot of electricity around fifty to sixty percent of what was needed during the months from March to September. Then biomass gasification

helped out during the months when there was not much sun from November, to February. Mid-scale systems and solar photovoltaic panels and biomass gasification all worked together to make this happen. Mid-scale systems were a part of this.

## 6.2 Environmental Performance and Land Requirements

Comparative environmental assessment demonstrated that system upscaling produced nonlinear increases in environmental impacts:

Scale Factor	CO <sub>2</sub> -eq Emissions (t/year)	Relative Emission Increase	PV Area (ha)	Biomass Plant + Storage (ha)	Total Land (ha)
1/500	14.4	Baseline	~2.0	~8–10	~10–12
1/250	25.6	~1.8×	~5.1	~10–15	~15–20
1/100	35.9	~2.5×	~9.9	~12–22	~22–30

Source: Bagheri et al. (2018).

When the system scale is doubled from 1/500 to 1/250 the atmospheric emissions go up by 1.8 times. When the system scale is expanded five times from 1/500 to 1/100 the emissions only go up by 2.5 times. This shows that the system scale, in the middle is more efficient.

The land that is needed for the system scale is different. At the system scale it needs 10 to 12 hectares of land. At the system scale it needs 22 to 30 hectares of land. Most of the land is used to store feedstock for the system scale, which's about 60 to 75 percent of the total land that is needed.

When we combine systems, like solar and wind power with other energy sources urban areas can really increase the amount of renewable energy they use. This is a deal because it helps them manage the times when the sun is not shining or the wind is not blowing. We can do this by using biomass, which's, like a steady backup and battery storage, which helps store extra energy for later. The people who study this like Bagheri and his team found out that this combination works well and they wrote about it in 2018.

## VII. SYNTHESIS: INTEGRATED FRAMEWORKS FOR SUSTAINABLE BIOPHILIC ARCHITECTURE

### 7.1 Thermal Comfort, Material Health, and Environmental Performance Integration

When we talk about architecture today it has to do three main things: keep people comfortable use healthy materials and be good for the environment. These things often conflict with each other. If we look at sustainable architecture in a smart way we can see that it is possible for sustainable architecture to achieve all these things at the same time. In fact,

sustainable architecture can even produce benefits in areas rather than having to choose between them. This is what sustainable architecture is, about finding ways to make sustainable architecture work well in all these areas, including thermal comfort, material health and environmental performance of sustainable architecture.

Thermal comfort in buildings that do not use a lot of machines to control the temperature depends on an important thing. These things are mass, which is the ability of materials to absorb and release heat, natural ventilation, which is the way air moves through a building and solar modulation, which is the way a building uses sunlight to warm or cool itself. Buildings made of earth and other local materials often have these characteristics.

These design strategies are also good because they use materials in a way and take advantage of local resources that can be renewed. This means that the energy used to make the materials for the building is low. Thermal comfort, in conditioned buildings and thermal mass and natural ventilation and solar modulation all work together to make a building comfortable.

Materials and earth materials are good for our health because they do not have bad things like volatile organic compounds, heavy metals and toxic processing.

Earth materials help keep the air clean and fresh by controlling the humidity. They do not give off bad smells like some other materials do.

This makes the air inside buildings better to breathe than the air in buildings that use drywall and other man-made materials as Asha Sapna and Anbalagan said in 2023.

Materials and earth materials are good for the people in the building and they are also good, for the earth because they do not hurt the environment as much when they are made.

The environment is affected by buildings in ways. We need to think about how buildings impact the environment from start to finish. This includes the energy they use when people are living or working in them. Some buildings are designed to stay cool or warm without using machines like air conditioners. These buildings show us that we cannot just look at the materials used to build them to see how they affect the environment. We also have to think about how energy they will use over time.

When we design buildings to connect people with nature it makes people like the building more. They feel a connection to the place and want to take care of it for a long time. This helps keep the building in condition and saves the environment. Environmental performance of buildings is very important. We need to think about the performance of buildings when we are building them and when we are using them. This way we can reduce the impact of buildings on the environment. Environmental performance is not about the materials we use to build it is also, about how much energy buildings use over their lifetime.

## 7.2 Design Integration Framework

To really make buildings that work well with nature and are good for the environment we need to think about how to put the things that make a building green. This means we have to consider the picture and the small details and we have to do this from the very start of the project. We are talking about principles and sustainable construction and we need to make sure these things are part of the plan, from the beginning. Biophilic principles and sustainable construction are important so we need to make a plan that includes principles and sustainable construction at every stage.

Site and Regional Context Phase: - Regional bioclimatic analysis identifying climate-specific passive design strategies (solar orientation, ventilation patterns, thermal mass requirements) - Local material availability assessment (earthen resources, timber, bamboo, agricultural residues) - Vernacular precedent analysis of region-adapted building strategies - Cultural and ecological attachment opportunities through indigenous materials and construction methods.

Building Envelope Design Phase: - Thermal mass integration through massive earthen or timber systems sized for regional thermal swings - Natural ventilation strategies through window placement, ventilation openings, and stack effect design - Solar modulation through strategic overhang design, vegetation, and orientation - Material selection prioritizing local, renewable, low-embodied-energy options with demonstrated health benefits

Interior Environmental Design Phase: - Natural light distribution through clerestories, light wells, and transparent interior partitions - Living systems integration (plants, water features, natural ventilation) providing direct biophilic engagement - Natural material visibility and sensory engagement through exposed structural systems, earth finishes, and wood surfaces - Thermal comfort provision through passive systems with occupant control options (operable windows, thermal mass interaction).

Operational Energy Integration Phase: - Hybrid renewable energy systems providing remaining operational energy requirements - Electrical load reduction through efficient lighting, appliance selection, and behavioral adaptation - Renewable energy generation from solar photovoltaic, wind, or biomass systems - Occupant engagement in energy monitoring and adaptive management.

## VIII. CONCLUSION

The way we design buildings is changing. We are starting to use design principles and sustainable construction practices together. This is a change in how we think about architecture. We are moving away from hurting the environment and towards helping it. At the time we are helping people's wellbeing. The information in this paper shows that combining design principles and sustainable construction practices is good for the environment, our health and our minds. Biophilic design principles and sustainable construction practices are making a difference, in many areas. Biophilic design principles are helping us and sustainable construction practices are too.

Earth construction is really good for the environment. It can be done in ways like using compressed stabilized earth blocks rammed earth and cob systems. These methods can reduce the impact on the environment by 62 to 91 percent. The best part is that

it does not have to be uncomfortable or ugly for the people living there.

In fact these earth materials are very good for our health. They help control moisture do not have chemicals and keep us warm or cool without needing a lot of extra systems. The natural look and feel of these materials with light and earthy colors also make people happy and connected to nature. This is because the materials and the way they are designed work with the environment. Earth construction is a way to build homes that are good, for people and the planet.

Vernacular architecture is really good at keeping people comfortable in kinds of weather. It does this without using machines to control the temperature. This is not an idea it is something that people have known about for a long time.

Scientists have studied how vernacular architecture works in different climates. They have looked at how buildings perform in the world and they have used computer models to understand how they work. What they found is that traditional design strategies are really effective.

People who live in buildings are usually very happy with them. In fact, studies have shown that between 70 and 95 percent of people are satisfied with their buildings. This is because people feel a connection to buildings that work well with the natural environment. This connection helps people take care of their buildings and keep them in condition for a long time. Vernacular architecture is, about making buildings that work well with the climate and this is something that we can learn from.

Bio-based materials that use leftovers from farms and forests are a way for developing regions to build things in a way that is good for the environment. They can use the things they have around them. Hire people from their own area to do the work. Using bamboo in mortar is an idea because it is good for the environment. This means that developing countries do not have to buy materials from places that are not good for the environment. Bio-based materials like these can help reduce the things we put into the air by 28 to 80 percent. This is really good for places that have a lot of bamboo. Bio-based materials are a choice, for these places because they have a lot of bamboo.

Hybrid renewable energy systems have to provide the rest of the energy that people need. When we design these systems, we need to think about the city and the people who live there. We have to make sure that the

systems are good for the environment and that they are fair for everyone.

Some systems are the right size and they try to balance being good for the environment and being cost effective. These systems show us that we should not just try to use much renewable energy as possible if it means we need a lot of land or if it bothers the people who live nearby.

If we get the people who use the energy involved in watching and managing the energy systems, they will be more likely to care about being sustainable. This is important, for renewable energy systems.

Future architectural practice must evolve beyond treating biophilic design and sustainable materials as optional enhancements to buildings designed by conventional methods. Rather, simultaneous optimization of thermal mass, passive ventilation, natural light, local materials, renewable energy, and occupant wellbeing must constitute the fundamental framework within which architectural expression develops. This integrated approach recognizes that environmental restoration and human flourishing represent complementary rather than competing objectives, achievable through design practice honoring both natural systems and human experience.

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