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Innovative Low-Carbon Construction Technologies for Energy-Efficient Housing and Sustainable Community Spaces

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Abstract

This 10-acre biophilic group housing project in Gurgaon redefines the future of living by seamlessly integrating low-carbon construction technologies with energy-efficient design. It exemplifies how biophilic architecture and smart building automation systems can work together in a harmonious, yin-yang relationship – balancing nature with technology to create sustainable, comfortable, and forward-thinking homes. Biophilia, with its emphasis on integrating nature into urban spaces, forms the heart of the project. Diverse greenery, alongside a mechanical, electricity-free irrigation system, ensures efficient water use while advanced drainage solutions prevent mosquito breeding. The staggered, Jenga-inspired balconies promote natural ventilation and abundant daylight, drastically reducing reliance on artificial climate control. These features foster a healthier, more natural living environment, enhancing the well-being of residents. At the other end of this balance, the building automation systems act as the technological backbone, optimizing energy use and operational efficiency. From floating glass technology that regulates sunlight and temperature to automated climate control systems that ensure comfortable indoor conditions, the smart technology complements the biophilic design. A fully automated basement system efficiently manages parking, surveillance, water systems, and fire safety, ensuring that the entire living experience is not only luxurious but also energy-efficient and cost-effective. Together, these two elements – biophilia and building automation – create a symbiotic relationship where nature and technology enhance each other. While biophilia brings the appeal of a green, serene environment, the automation systems make this future of living practical, sustainable, and efficient. This development sets the stage for future housing projects that blend luxury and eco-consciousness, demonstrating that a balance of both can redefine urban living.

Keywords: Future of living, low-carbon construction, biophilic design, building automation, energy efficient housing

INTRODUCTION

The construction sector has long been associated with significant environmental impacts, especially in terms of carbon emissions and energy consumption. As the global population increases and urbanization intensifies, the demand for housing and community spaces has surged, further exacerbating these environmental pressures. In response to this growing concern, low-carbon construction technologies and energy efficiency have become central to modern architectural and urban planning strategies. These approaches aim to minimize the ecological footprint of buildings, reduce energy usage, and create more sustainable living environments.

The integration of low-carbon technologies in housing and community spaces is particularly

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relevant in densely populated and rapidly urbanizing countries like India. With cities like Gurgaon evolving into major economic hubs, there is a need for innovative construction solutions that not only meet the housing demand but also align with environmental sustainability goals. The shift towards biophilic designs – such as those in the 10-acre group housing project in Gurgaon – demonstrates a commitment to reducing carbon footprints while creating healthier, more livable spaces.

The height of luxury housing can be usually seen as going in two directions, large spacious apartments at higher floors, or large homes with adjoining gardens or natural features [1].

With India becoming the most populated country on the planet, vertical space is a soon diminishing currency. We need to come up with a way to plan housing vertically in a way to give ample space to people while using minimum area at the ground level [2].

This paper explores the application of low-carbon construction technologies for future housing, with a particular focus on a biophilic group housing project in Gurgaon. This development is a pioneering example of how sustainability, energy efficiency, and biophilic principles can be integrated into the urban landscape to redefine modern living standards. The paper also examines the challenges and solutions encountered during the design and implementation of such projects, offering insights into how future housing developments can incorporate similar technologies to achieve low-carbon and energy-efficient outcomes.

LITERATURE REVIEW

Futuristic Housing

Diverse Aspects and the Yin-Yang of Biophilia and Smart Systems

Futuristic housing can take on various forms, each offering unique features that cater to modern-day demands for sustainability, luxury, and advanced technology. These diverse aspects of future group housing might include,

- *Floating or Submerged Homes:* Housing designed to adapt to rising sea levels, using floating platforms or underwater structures, offering a unique aquatic lifestyle while addressing environmental concerns.
- *Vertical Farms Integrated into Housing:* Homes that come with their own farming systems, allowing residents to grow food in urban environments, promoting self-sufficiency and reducing carbon footprints.
- *3D-Printed Housing:* Entire communities built using 3D printing technology, drastically reducing construction time and costs while also minimizing material waste.
- *Self-Healing Materials:* Buildings constructed from innovative materials that can automatically repair minor damage, increasing longevity and reducing the need for constant maintenance.
- *Hyper-Connected Smart Cities:* Housing units that are part of a fully connected smart city, with integrated AI-driven infrastructure managing traffic, energy distribution, waste management, and even social services.

While each of these approaches represents a bold step toward futuristic living, the yin-yang balance of biophilia and smart automation stands out as the ideal combination for luxury group housing.

Biophilia brings the luxury of nature into urban environments. Large green spaces, open-air designs, and natural elements create an unparalleled sense of tranquility and well-being. High-end luxury homes typically fall into two categories: either lavish penthouses that dominate the skyline or expansive properties with abundant greenery. Biophilic group housing fuses these two worlds, offering both the vertical luxury of high-rise living and the serenity of nature. For those who seek status, comfort, and environmental harmony, biophilic housing is the perfect appeal.

However, while the natural world provides luxury, the complexity of maintaining such an environment in urban settings can be overwhelming. This is where smart systems step in, making this

dream more practical. A comprehensive building automation system controls everything from climate management and water systems to security and energy use. While not necessarily the most glamorous selling point, these systems ensure that the housing remains energy-efficient, low-maintenance, and sustainable. They reduce the effort of managing green areas, optimize energy use through AI and sensor-driven adjustments, and ultimately enhance the quality of life while lowering operational costs.

In essence, biophilic housing appeals to the emotional and aesthetic desires of future residents, providing luxury through connection with nature, while smart automation systems provide the practicality and cost-effectiveness to make such developments sustainable and energy efficient. Together, they represent the future of luxury group housing: opulent, eco-friendly, and technologically advanced.

Trends Tracking to Smart Biophilia

An online survey was conducted to try and understand the housing requirements and interest of people to deem the project viable at all.

The sample questions were asked including their age and their choices relating to the experiment to establish a need for biophilic architecture as a possible efficient solution as well as the future of luxury housing. The following questions were asked.

- What is your name?
- What is your age?
- What city are you currently living in and what is your hometown?
- What is your current living situation?
- How important is having access to green spaces in your living environment?
- What is your ideal type of home?
- If you had to choose, how likely are you to wish to live in a biophilic futuristic home on a higher floor compared to a traditional house with a garden?
- What factors influence your decision to live in a biophilic futuristic home?
- What concerns do you have about lived in a biophilic futuristic home?
- Please share any additional thoughts or comments regarding your housing preferences.

These questions provided an insight into the growing trends and to understand the requirements of the future residents of the housing, the potential problem of which this paper aims to try and provide a viable solution for.

CASE STUDIES

To contextualize the biophilic housing project in Gurgaon within the broader landscape of low-carbon construction, it is important to examine other global examples of similar developments. The following case studies highlight various approaches to integrating sustainability and energy efficiency in housing and community spaces.

Bosco Verticale, Milan, Italy

The Bosco Verticale, or Vertical Forest, (Figures 1–3) in Milan is one of the most well-known examples of biophilic design in urban housing. Completed in 2014, this residential tower features over 900 trees and thousands of shrubs and plants, creating a living façade that provides natural insulation and improves air quality. The building's design reduces energy consumption by shading apartments and minimizing heat absorption. The vegetation also helps to filter dust particles from the air, contributing to healthier living conditions.

INFERENCES

- The site has a subtropical humid climate vs India's tropical streppe with the main difference is India is much hotter and can therefore not sustain as much greenery on the building's facade, also the

materials to be used must differ.

- Services have been done using the regular overhead tank distribution system which is the most efficient.
- Staggered balcony concept for privacy and natural sunlight for plants.
- Big open spaces showing a connection to nature even at the individual unit level.
- Vehicular circulation at periphery to avoid accidents via cars and to keep the site clear for biophilic and architectural programs.
- Plenty of pedestrian circulation to assure a good visual experience for jogging or walking and for interconnectivity.

Figure 1. Bosco Verticale, Milan.

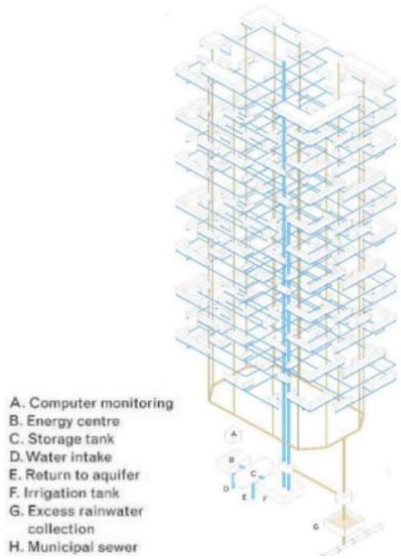

Figure 2. Services in Bosco Verticale.

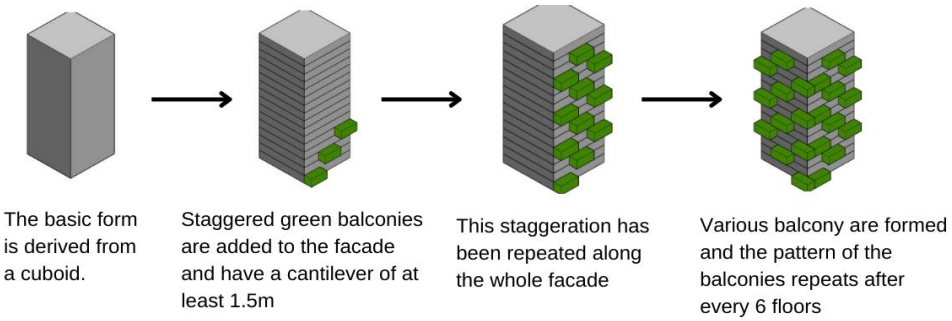

Figure 3. Form development of Bosco Verticale.

Case Study: Qiyi City Forest Garden – Lessons in Biophilic Design Failure

The Qiyi City Forest Garden in Chengdu, China (Figure 4), is a cautionary tale in the execution of biophilic design. The project aimed to create a verdant urban oasis by incorporating extensive greenery into residential towers, with the promise of cleaner air, natural beauty, and improved well-being for residents. However, the ambitious project quickly encountered major setbacks, primarily due to poor maintenance and ineffective ecological management.

Figure 4. Qiyi City Forest, Chengdu, China.

One of the critical issues was the proliferation of mosquitoes, a problem exacerbated by stagnant water in plant containers and a lack of proper drainage systems. The unchecked growth of vegetation also created breeding grounds for pests, overwhelming the intended benefits of a nature-filled environment. Without adequate pest control and water management, what was envisioned as an idyllic biophilic residence became uncomfortable and unhealthy for residents, many of whom left the complex.

The failure of Qiyi City Forest Garden highlights the importance of thoughtful planning and sustained ecological management in biophilic design. A successful biophilic project must ensure that greenery is properly maintained, water systems are well-managed, and pests are controlled to prevent the natural environment from becoming a liability. This case underscores the balance that needs to be struck between nature integration and urban livability.

INFERENCES

Importance of Ecological Management

The failure of Qiyi City Forest Garden underscores the need for effective water drainage and pest control systems in biophilic designs to prevent stagnant water and mosquito breeding.

Sustained Maintenance Is Critical

Regular upkeep of plants and greenery is essential to prevent overgrowth and the subsequent attraction of pests**,** maintaining both the aesthetic and health benefits of biophilic environments.

Balance Between Nature and Urban Comfort

While integrating nature into urban housing has many benefits**,** failing to manage it properly can make the living space uncomfortable and even harmful**,** driving residents away.

Comprehensive Design Planning

Biophilic designs must include comprehensive planning for irrigation**,** drainage**,** and pest control from the beginning to ensure a successful long-term living environment.

Learning from Failures

The Qiyi City Forest Garden serves as a reminder that not all biophilic projects succeed**,** but the lessons learned from their failures can help improve future projects**,** ensuring nature integration enhances rather than detracts from urban living spaces.

Need for Biophilia and Automated Building Construction

Biophilia, a concept rooted in the innate human connection to nature, has gained significant traction in contemporary architecture and urban planning. As cities continue to expand and urbanization accelerates, the need for biophilic design in the built environment becomes increasingly important. This need arises not only from an environmental standpoint but also from the growing recognition of its psychological, physiological, and social benefits for people living in densely populated urban areas.

Human Well-Being and Health Benefits

One of the primary reasons biophilia is becoming essential in modern design is its profound impact on human well-being. Numerous studies have shown that exposure to nature, even in urban environments, has a positive effect on mental health, reducing stress, anxiety, and depression. Natural elements like greenery, water features, and daylight can improve mood, increase productivity, and foster a sense of tranquility and balance.

For instance, in hospitals, patients with access to views of nature or natural light have been found to recover more quickly than those in traditional, sterile environments (Ulrich, 1984). Similarly, workplaces incorporating biophilic elements report higher levels of employee satisfaction, reduced absenteeism, and improved cognitive function. In residential settings, integrating natural elements can enhance residents' quality of life, helping them feel more connected to their surroundings and promoting physical and mental health.

Environmental Sustainability and Energy Efficiency

Biophilic design contributes to environmental sustainability by encouraging the use of natural processes and materials. Buildings designed with biophilic principles often include features like natural ventilation, daylighting, and green roofs, which help reduce energy consumption for heating, cooling, and lighting. The use of plants, trees, and water bodies in and around buildings can provide natural cooling, regulate temperature, and reduce urban heat islands, making cities more climate resilient.

Moreover, biophilia supports the broader goals of sustainability by encouraging architects and urban planners to consider how the built environment can coexist harmoniously with the natural world. Green roofs, living walls, and vertical gardens not only improve air quality by absorbing CO_2 and filtering pollutants but also provide habitats for birds, insects, and other wildlife, promoting biodiversity in urban areas.

Addressing the Disconnection from Nature

In today's highly urbanized societies, many people, particularly in densely populated cities, experience a disconnect from nature. This disconnection has been linked to a variety of social and health issues, including the rise of "nature-deficit disorder" which refers to the negative consequences of humans spending less time in natural environments. This growing distance from nature has led to diminished physical activity, poorer mental health, and weaker social connections.

Biophilic design seeks to bridge this gap by incorporating elements of the natural world into urban spaces. By integrating parks, community gardens, green public spaces, and nature-infused buildings, cities can reconnect their inhabitants with nature, even within the urban core. This not only provides individuals with a respite from the stresses of urban life but also fosters stronger community ties and a sense of place.

Cultural and Aesthetic Value

Biophilic design also taps into cultural and aesthetic values that many societies associate with nature. From the Zen gardens of Japan to the lush landscapes of tropical regions, humans have long sought to integrate nature into their living environments. Biophilia enhances the aesthetic quality of urban spaces, making them more visually appealing and emotionally resonant.

Incorporating biophilia into architecture and urban planning can reflect cultural values, respect historical traditions, and create spaces that are not only functional but also beautiful and inspiring. Cities with biophilic elements tend to have a more appealing visual landscape, attracting residents and visitors alike, thus enhancing economic value and community pride.

Improving Social Cohesion and Public Spaces

Public spaces designed with biophilic principles can serve as gathering points that strengthen social cohesion. Green spaces encourage social interaction and provide opportunities for people to engage with their communities, fostering a sense of belonging and shared responsibility for the environment. Urban parks, community gardens, and nature-oriented recreational areas offer inclusive spaces where diverse groups of people can come together.

Biophilic design also makes public spaces more inviting and comfortable. Trees and plants provide shade and cooling, making outdoor spaces more usable during hot weather, while natural elements create a calming atmosphere that promotes positive social interactions. This is particularly important in large cities, where many residents live in high-density housing with limited access to private green spaces.

Resilience in Urban Development

With climate change and urbanization posing significant challenges to cities worldwide, biophilic design is increasingly seen as a critical tool for creating resilient urban environments. Natural systems integrated into the built environment can help mitigate the effects of extreme weather events, such as heatwaves, flooding, and poor air quality. Green roofs, permeable surfaces, and rain gardens, for example, help absorb rainwater, reducing the risk of flooding and easing pressure on city drainage systems.

Furthermore, incorporating vegetation in and around buildings can help manage heat by providing shade and cooling through evapotranspiration, reducing the need for air conditioning and decreasing overall energy demand. As cities continue to face the challenges of urban heat islands, pollution, and resource shortages, biophilic design offers a sustainable approach to creating urban spaces that are more adaptable to environmental stresses.

Smart Automation Systems in Housing

Smart automation systems in housing are revolutionizing how homes operate by integrating technology to manage essential functions like energy consumption, water usage, and security. These systems create more sustainable and efficient living spaces by automating processes, such as heating, ventilation, lighting, and water management, ensuring that homes are not only comfortable but also environmentally responsible.

In housing, smart automation systems allow for real-time monitoring and adjustment based on factors, such as occupancy and external conditions. For example, heating and ventilation systems can adjust temperatures based on the time of day, weather, or the presence of residents, reducing unnecessary energy consumption while keeping the home comfortable. Similarly, automated lighting systems can detect natural light levels and adjust artificial lighting accordingly, or turn off lights in unoccupied areas, further reducing electricity use.

Water management is another critical feature of smart systems in housing. Mechanical, electricity-free irrigation systems can be used to maintain gardens or green spaces without wasting water. These systems use pressure or gravity to distribute water efficiently, preventing issues, such as stagnation that can attract mosquitoes or harm plant health, which is especially important in homes that incorporate biophilic designs with extensive greenery.

Additionally, smart automation systems enhance home security and safety by integrating fire alarms, surveillance systems, and automated access control. This comprehensive approach allows homeowners to monitor and manage security remotely, adding convenience and safety to the living experience.

Overall, smart automation systems in housing contribute to energy efficiency, sustainable water use, and enhanced security, offering a future-proof solution to modern residential living.

Sustainable Construction Technologies and Biophilic Design

Over the past few decades, sustainable construction technologies have evolved significantly, driven by the urgent need to mitigate climate change and reduce the environmental impacts of urbanization. According to the World Green Building Council, buildings account for nearly 40% of global carbon emissions, with energy consumption in residential and commercial buildings being a major contributor. To address this, architects and urban planners have increasingly adopted low-carbon technologies that not only reduce emissions during construction but also enhance energy efficiency throughout a building's lifecycle.

A key concept in sustainable construction is the use of renewable energy sources, such as solar power, along with energy-efficient systems that minimize reliance on non-renewable resources. Photovoltaic (PV) panels, for example, are increasingly being incorporated into building designs to harness solar energy, significantly reducing the building's carbon footprint. Additionally, advanced insulation materials, energy-efficient windows, and smart climate control systems are being employed to reduce energy consumption, particularly in cooling and heating systems, which account for a large portion of energy use in buildings.

Biophilic design, a relatively recent concept in architecture, emphasizes the integration of natural elements into the built environment. This approach is based on the idea that human beings have an innate connection with nature, and incorporating natural elements into architectural design can enhance well-being and improve quality of life. In the context of low-carbon construction, biophilic design plays a crucial role in reducing energy consumption by utilizing natural ventilation, daylighting, and passive cooling strategies. Research has shown that buildings designed with biophilic principles tend to have lower energy demands due to their reliance on natural systems for heating, cooling, and lighting.

Figure 5. A regular Jenga and the Concept Model for the Form of the Project.

Form of the project was inspired by the Jenga concept (Figure 5), the stacking of floors in a non-directly repetitive way so as to get double height for most apartment balconies so as to get a far better reach of sunlight and double height for taller vegetation. Final form is a mixture of stacking concepts with repetitive forms on alternate floors.

Figure 6. Cascading balconies to provide double heights for the green garden areas.

Problems

Common problems were found in the ideation.

Biophilic

Case studies mentioned adobe showcased two major issues in biophilic group housings (Figure 6). They are areas which can have issues with water supply and/or drainage which can cause issues. Bosco Verticale solved this issue by using thousands of different mosquito repellent species of shrubs and plants. Another additional issue was the supply of water and the drainage of it. One way to handle this can be via a periodic supply of water to the plant via electrical connection to the smart aspect of the building but that is a completely avoidable issue. It could also be solved via usage of completely mechanical drain water as rainwater is a completely content source of water for the area [3].

The solution was a sophisticated irrigation system that distributes water efficiently and prevents stagnation, along with varying plant species which fend off pests ensuring that the plants thrive without creating an environment conducive to mosquito breeding. This system is highly energy-efficient and relies on rainwater harvesting to reduce the building's water consumption (Figure 7).

Figure 7. Detail showing a completely mechanical irrigation system to provide water to the gardens and draining them timely.

In the coming future (Figure 8), it is expected that the soil fertility and the farmable soil available will decrease significantly and thus it is safe to assume that we could have a severe food shortage, especially considering the population explosion expected in the upcoming years. Even presently, Indian soil is lacking in the nutrients that are essential for adequate fertility of the soil. In India, an analysis of

over 2 lakh soil samples revealed that, on average, 36.5% of soils were deficient in zinc; 23.4%, in boron; 12.8%, in iron; 7.1%, in manganese and 4.2%, in copper.

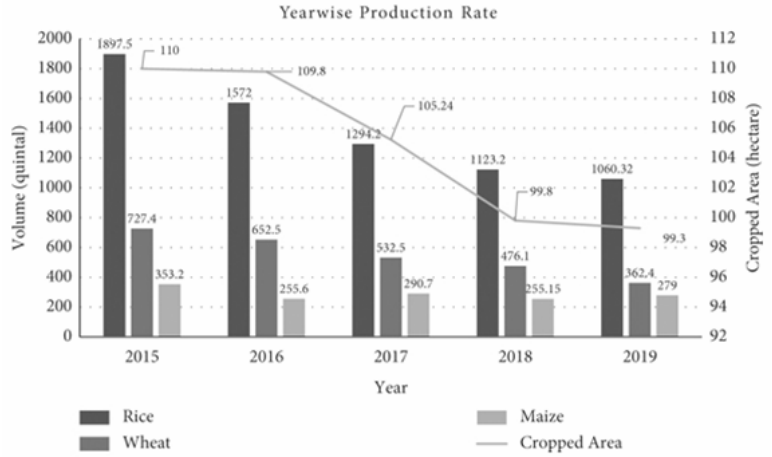

Figure 8. Graph showcasing the decreasing fertility of soil throughout the years.

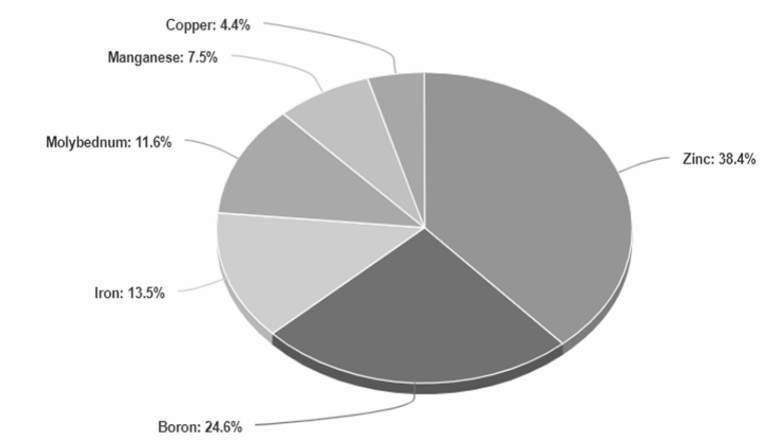

Figure 9. Micronutrient deficiency in Indian soil.

Smart Building System

The future is moving towards smart homes (Figure 9). They make life easy, and they help with energy conservation and maintenance and running costs for a home. After a certain point, the question arises as to when does a building go beyond basic automatic appliances to becoming "sentient". Does it become sentient if its basic objective is to make the residents' life easier rather than biological sentience which is hard coded for creatures to survive? If the home knows if the resident is at home, can take care of lighting, ventilation etc. knowing all of it is not necessary when the user is not home, knows how to keep the resident comfortable and safe, does it become sentient [4]?

These are the various parameters explored in this project:

- Admin system.
- Lighting.
- Water supply.
- Water drainage.
- Fire security system.
- Accessibility and Security.
- Ventilation and HVAC.
- Various vanity sensors.

Solution

- *Admin system:* Formulation of various control center nodes to get a building with various amount of complex interdependent systems to function as single coherent organisms are being developed [5].
- *Lighting:* Study on various NBC and Local Codes to get the minimum amount of Lighting levels and lux levels required. Arrange for products which can accomplish the minimum amount of lighting using a minimum amount of light level to add to existing lighting level from the surrounding areas.
- *Water supply:* Automatic water supply systems for uninterrupted water supply. Sensors to keep a check on the water supply levels and sensors to make sure that water is not being wasted and for easy water measurement.
- *Water drainage:* Arrangements to be made to treat gray water to relate to an overhead tank for using the process of addition of nutrients for aquaponics [6].
- *Fire security system:* A custom fire system which first detects a fire, checks for occupants and then either uses a seal and water spray system (Cheaper and faster and more effective but can create water vapor harming an occupant) or accessibility and co2 system (needs to be replaced, more expensive but better for an occupant present in the room)
- *Accessibility and security:* Making systems and routes for direct and convenient access for residents and visitors while not compromising security.
- *Ventilation and HVAC:* A lot of temperature and air quality control is assumed to be handled due to the prominent biophilic presence, regardless, air quality sensors as well as a central ac system with temperature-controlled louvers to handle temperature.
- Various vanity sensors to make the home as automatic as possible, such as automatic taps, flushes, automatic fragrance dispensers.

Use of Materials

- *Bricks:* Most common element in today's building construction. It is cheap and readily available. Used to build the carcass of the building in rat trap bond to fight against harsh Indian climate).
- *AAC Blocks:* to be used in construction for all internal walls and is better for the environment [7].
- *Self-healing concrete:* To be used in columns [8].
- *Frosted Glass and Electrochromic Glass:* Frosted glass for privacy and energy efficiency, it can keep out harsh lights during daytime, used in railings and bathroom partitions. Electrochromic glass for controllable amount of light entering at any time, used for apartment windows.
- *Ashcrete:* Used in pavements, eco-friendly [9].

ANALYSIS

The Gurgaon biophilic group housing project represents a significant step forward in the integration of low-carbon construction technologies and energy efficiency in residential developments. By combining biophilic design principles with advanced automation systems, renewable energy sources, and energy-efficient materials, the project demonstrates that it is possible to create environmentally sustainable housing that meets the needs of modern urban dwellers.

The project's emphasis on targeting business owners as early investors has had a profound economic impact on the surrounding area, attracting wealth and fostering further development. At the same time, the project's scalability and replication potential make it a model for future housing developments in similar urbanizing regions, both in India and globally.

However, challenges remain in terms of cost, maintenance, and social inclusivity. As low-carbon technologies continue to evolve and become more affordable, the potential for widespread adoption increases. With the right policies and incentives in place, future housing projects can achieve both environmental sustainability and social equity, creating more livable, resilient, and energy-efficient urban spaces.

The Gurgaon project is set to be a far more sustainable and energy efficient idea due to it taking its heavy inspiration from Bosco Verticale in Milan; Bosco Verticale being a fantastic example of a building that encapsulates the themes of 2019's World Green Building Week "Building Life" campaign, with its innovative ways of thinking to create its stunning green façade [10].

According to The Impact of Smart Homes on Energy Efficiency and Sustainability by Mohd Aarif Smart homes are far more energy efficient [11].

Studies also showed a very efficient symbiotic relationship between biophilia and smart home operating systems [12–14].

CONCLUSIONS

This paper outlines a visionary approach to group housing that combines biophilic design principles with cutting-edge building automation systems, offering a potential blueprint for the future of sustainable living. By integrating low-carbon construction technologies with energy-efficient architecture, this model addresses key urban challenges – such as environmental impact, energy consumption, and resident well-being – while also offering a luxurious and modern living experience.

The balance between nature and technology creates a harmonious, sustainable environment where residents can enjoy the best of both worlds: the tranquility and health benefits of biophilia, and the convenience and efficiency of smart, automated systems. As the demand for eco-conscious and cost-effective housing grows, this project serves as a potential prototype for future developments, paving the way for more resilient and sustainable urban communities.

Through its innovative approach, this paper presents a possible future for group housing—one where the fusion of natural and technological elements creates homes that are both environmentally responsible and highly livable. The concepts explored here have the potential to redefine how we think about residential developments, setting a new standard for the future of group housing.

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