Optical Fiber Concrete: The Future of Sustainable Urban Infrastructure

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Abstract. Concrete is one of the most widely used construction materials; however, its opaque nature limits the utilization of natural daylight and increases dependency on artificial lighting. To address this limitation, Optical Fiber Decorative Concrete (OFDC) has been developed by embedding polymer optical fibers within the concrete matrix to enable controlled light transmission without significant loss of strength.

This study presents the experimental development and evaluation of OFDC panels intended for architectural, decorative, and sustainable urban applications. Concrete panels incorporating 2%, 4%, 6%, and 8% optical fiber volume fractions were fabricated using OPC 53-grade cement and polymer optical fibers of 2 mm diameter. Mechanical performance, workability, water absorption, and light transmission characteristics were experimentally assessed after 28 days of curing.

The results indicate that OFDC panels with 4–6% fiber content provide an optimum balance between compressive strength and daylight transmission, achieving up to 18% light transmission while maintaining acceptable compressive strength levels. An economic and energy analysis suggests that the use of OFDC can reduce artificial lighting demand by approximately 15–20%, resulting in a payback period of 2–3 years for façade applications.

The findings demonstrate that OFDC is a viable material for energy-efficient, aesthetically enhanced, and sustainable construction, particularly for non-structural and architectural components in urban infrastructure.

Keywords: Optical Fiber Decorative Concrete, Light-Transmitting Concrete, Energy Efficiency, Sustainable Materials, Urban Infrastructure.

1 Introduction

Concrete is one of the most widely used materials in the construction industry because it is strong, durable, and affordable. However, one limitation of normal concrete is that it is opaque, which prevents natural light from passing through. This often

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increases the use of artificial lighting inside buildings and leads to higher energy consumption. With the growing need for sustainable and energy-efficient construction materials, there is a demand for new types of concrete that combine strength with environmental benefits.

Optical Fiber Decorative Concrete (OFDC), also known as light-transmitting concrete, is one such innovation. It contains optical fibers that allow natural light to pass through the concrete without reducing its strength. This feature not only improves the visual appeal of structures but also helps in saving energy by reducing the dependence on artificial lighting. The concept of transparent concrete first gained attention in the early 2000s [1] with the development of LiTraCon in Hungary. Since then, research and applications have expanded globally [2-6], though mostly for small-scale decorative elements and architectural features. In India, this technology is still at an early stage and has not yet been widely adopted in large construction projects.

The present study aims to design and test OFDC panels and molds to evaluate their mechanical strength, light transmission ability, and potential for sustainable construction. In addition, special attention is given to developing molds for creative uses such as decorative wall panels, logo-embedded surfaces, flooring materials, and building façades. Through this approach, the study highlights how OFDC can serve as both a functional and aesthetic material for modern architecture and energy-efficient design [5, 7,15].

Today, buildings are expected to do more than just provide strength and shelter. They are also required to save energy, make better use of natural resources, and create comfortable spaces for people. One of the simplest ways to reduce energy use in buildings is by allowing more natural light during the daytime. However, most concrete structures block light completely, which increases the use of artificial lighting even when sunlight is available.

Optical Fiber Decorative Concrete offers a simple and creative solution to this problem. By placing thin optical fibers inside concrete, light can travel through the material from one side to the other. The concrete still behaves like normal concrete in terms of strength, but it also gains a unique glowing effect when exposed to light. This makes the material useful not only for construction but also for decorative and architectural purposes.

Unlike glass or transparent panels, this type of concrete remains solid and safe while allowing light to pass through in a controlled manner. Because of this, it can be used in places where glass may not be suitable, such as wall panels, partitions, flooring elements, nameplates, logos, and façade features. The use of polymer optical fibers also helps in making the material durable and easier to handle during casting and installation.

Although the idea of light-transmitting concrete has been known for some time, its use is still limited, especially in developing countries. High cost, difficulty in placing fibers, and lack of practical testing are some of the main reasons. Therefore, there is a clear need for experimental studies that focus on simple production methods and realistic applications. This study aims to explore these aspects by developing Optical Fiber Decorative Concrete panels and evaluating their strength, light-passing ability, and suitability for practical use.

2 Literature Review

Optical Fiber Decorative Concrete (OFDC), also referred to as light-transmitting or transparent concrete, has gained attention due to its ability to transmit natural light while maintaining the basic mechanical properties of conventional concrete. By embedding optical fibers within a cementitious matrix, daylight can pass through solid concrete elements, enhancing visual appeal and reducing dependence on artificial lighting. Previous studies consistently report that light transmission increases with higher fiber content; however, a marginal reduction in compressive strength is also observed. Despite these promising characteristics, most existing research emphasizes large-scale or prefabricated panels, which are costly and impractical for small decorative elements or local construction applications. Consequently, the adoption of OFDC in economical, small-scale formats remains limited.

In addition to optical performance, durability and long-term serviceability are critical considerations for OFDC applications. Research on crystalline admixture concrete demonstrates that crystalline compounds formed through reactions with cement and water can seal pores and micro-cracks within the concrete matrix. This self-sealing action reduces water permeability, restricts chloride penetration, and protects reinforcement from corrosion. Such durability-enhancing mechanisms are particularly relevant for OFDC elements exposed to environmental moisture or aggressive conditions, as they help maintain both structural integrity and optical performance over time [2-10].

Studies focusing on pervious and modified concrete systems provide further insights into performance optimization through mix design and curing practices. The use of chemical admixtures, including hybrid poly-carboxylate polymers, has been shown to improve bonding between aggregates and cement paste, leading to better compactness and strength development. Internal curing techniques have been found to support hydration more effectively than conventional curing in certain cases, resulting in improved mechanical performance. These findings highlight the importance of controlled hydration and curing strategies for achieving consistent quality in OFDC production [11, 12].

With increasing concerns over water scarcity, recent investigations have introduced smart curing approaches using Internet of Things technology. Sensor-based curing systems monitor moisture and temperature in real time and supply water only when required, reducing water wastage while ensuring adequate strength gain. Such systems are particularly beneficial for OFDC, where controlled curing can help minimize surface defects and maintain fiber alignment [13-14].

Overall, the literature indicates that while OFDC has strong potential as an energy-efficient and visually appealing building material, there is a lack of research on affordable, small-scale, and locally adaptable production methods. The integration of optimized fiber content, durability-enhancing admixtures, and efficient curing techniques remains largely unexplored. The present study addresses this gap by developing cost-effective OFDC prototypes and experimentally evaluating their structural, durability, and daylighting performance for practical application [15-22].

3 Research Gap

Even though optical fiber concrete has been tested in many labs, there are still some areas that need more study:

3.1 Limited Use in Products

Most research has been done on small concrete blocks or panels. Very few studies have tried to make real products like tables, basins, flooring, or wall panels with designs and logos.

3.2 Uses in Buildings

Only a few studies have looked at how this material can be used in big buildings, like for walls or façades, which can help make buildings more eco-friendly.

3.3 Energy Saving

Some studies show that this concrete lets light pass through, but there is not much research that measures how much electricity it can actually save in real buildings.

3.4 Durability and Maintenance

Long-term performance is not well known. More tests are needed to see how strong it stays outdoors in different weather conditions.

3.5 Making and Cost Problems

It is difficult to place the optical fibers correctly, and that increases the cost, making it hard to produce on a large scale.

3.6 No Design Rules

There are no clear design standards or guidelines for using this type of concrete in construction or decorative work.

4 Objectives

4.1 Product Development and Innovation

To develop Optical Fiber Decorative Concrete that can be used to make different types of products such as wash basins, table tops, decorative panels, branding elements, and art pieces.

To design creative and customizable OFDC products that can be used for both building and commercial purposes, adding beauty and uniqueness to modern construction.

4.2 Architectural and Interior Applications

To use OFDC in building elements like flooring, façades, and wall designs in order to achieve a good balance between strength, appearance, and durability.

To make use of OFDC's light-transmitting property to increase natural lighting in buildings and reduce the need for artificial lighting, thereby saving energy.

4.3 Performance Evaluation and Testing

To test the strength, workability, and overall performance of OFDC and compare it with normal concrete.

To study how well OFDC passes light and check its suitability for decorative, interior, and architectural uses.

5 Problem Statements

Traditional concrete does not allow light to pass through, which increases the need for artificial lighting and results in higher energy use. While decorative concrete improves how a structure looks, it does not make it more sustainable.

There is a need for a new type of concrete that can:

Keep its strength while allowing natural light to pass through.

Be used for making different products such as basins, tables, platforms, logos, and floor finishes.

Enhance the appearance of building exteriors and reduce dependence on artificial lighting.

Provide real energy-saving benefits when used in actual buildings, not just in experiments.

Be affordable and easy to produce, even when optical fibers are added on a large scale.

6 Methodology

This study adopted a structured experimental methodology to investigate the performance of concrete incorporating optical fibers. The experimental program focused on evaluating the effects of varying optical fiber content on the mechanical, durability, workability, and light-transmitting properties of concrete panels. All materials, mix proportions, and testing procedures were selected in compliance with relevant Indian and international standards to ensure accuracy and reproducibility.

6.1 Materials

The materials employed in the experimental investigation are summarized below:

• Cement: Ordinary Portland cement of 53 grade, complying with the requirements of IS 12269, was used as the primary binding material.

• Fine Aggregate: Natural river sand conforming to Zone II grading, as specified in IS 383.

• Coarse Aggregate: Crushed angular coarse aggregates with a nominal maximum size of 20 mm, conforming to IS 383.

• Optical Fibers: Polymer-based optical fibers of 2 mm diameter were used to facilitate light transmission through the concrete matrix.

• Water: Clean potable water, free from harmful contaminants and meeting the requirements of IS 456 [22], was used for mixing and curing.

6.2 Mix Proportioning

The concrete mix proportions were determined in accordance with the guidelines provided in IS 10262:2019 [23]. A reference mix without optical fibers was prepared, along with modified mixes containing optical fibers at volumetric proportions of 2%, 4%, 6%, and 8%. To maintain uniformity and enable effective comparison between mixes, the water–cement ratio was kept constant throughout the experimental program.

6.3 Panel Casting and Fiber Arrangement

Concrete panels were cast using specially designed molds to accommodate the placement of optical fibers. The fibers were positioned in straight, parallel alignments across the thickness of the panels to achieve consistent and effective light transmission. Particular attention was given to maintaining uniform spacing and proper alignment of fibers during casting.

Concrete was placed gradually into the molds to prevent fiber displacement and material segregation. Controlled compaction was applied to remove entrapped air while preserving the intended fiber orientation. The specimens were demolded after 24 hours and subsequently cured by water immersion for a period of 28 days under laboratory conditions.

6.4 Specimen Preparation

For each fiber content level, three specimens were prepared for every test conducted. The mean value of the results obtained from these specimens was considered for analysis to reduce experimental variability and improve result reliability.

All panels were cast with uniform dimensions of 234 mm × 110 mm × 40 mm, ensuring consistency in testing conditions and comparative evaluation.

6.5 Testing Procedures

Upon completion of the curing period, the specimens were subjected to the following tests:

6.5.1 Compressive Strength Test

The compressive strength of the concrete specimens was evaluated in accordance with ASTM C39 [24] to determine the effect of optical fiber inclusion on load-bearing performance [2, 6, 16].

6.5.2 Slump Test

The workability of fresh concrete was assessed using the slump test, conducted as per the provisions of IS 1199.

6.5.3 Light Transmission Test

Light transmission characteristics of the concrete panels were measured using a digital lux meter. Light intensity values were recorded at both the exposed and opposite surfaces of the panels under controlled lighting conditions [7, 9, 15,19].

6.5.4 Durability Test

Durability was examined through water absorption tests, carried out according to applicable standards, to evaluate the influence of optical fibers on concrete permeability and moisture resistance.

6.6 Methodological Significance

The adopted experimental methodology enabled a systematic evaluation of the impact of optical fiber content on the functional and mechanical performance of concrete. The approach ensured consistent testing conditions and produced reliable data, supporting the assessment of optical fiber concrete as a viable material for architectural and sustainable construction applications.

This method helped achieve consistent results and gave dependable information about the strength and light-transmitting ability of the panels

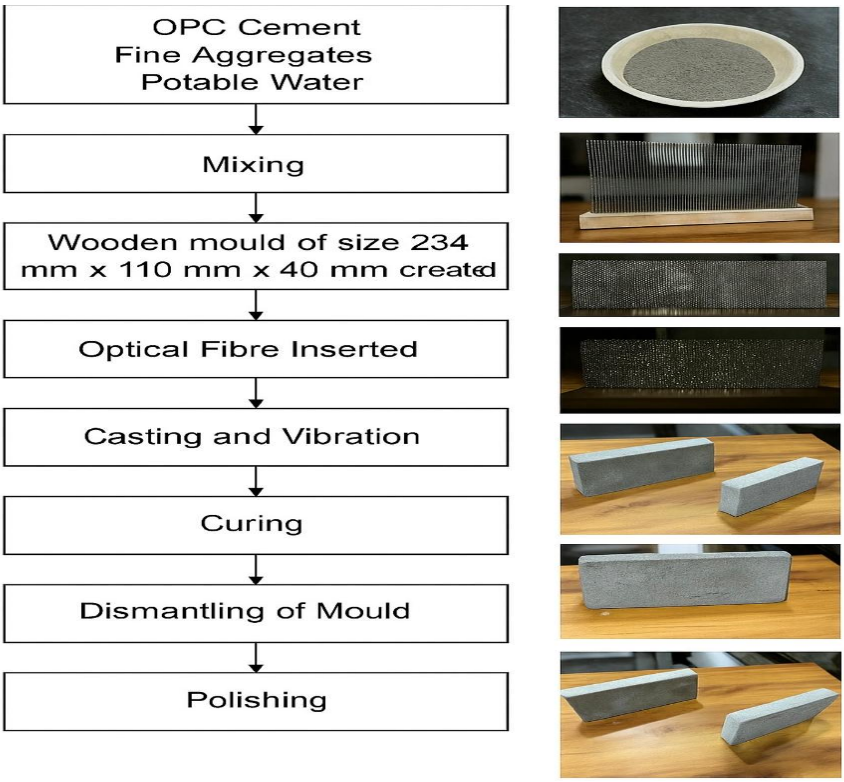

Fig. 1. Stepwise flowcharts showing the production process of Optical Fiber Decorative Concrete (OFDC) including material mixing mold preparation, optical fiber insertion, casting, curing, and finishing.

Fig. 2. Prototype mold and Optical Fiber Decorative Concrete (OFDC) samples developed by the author.

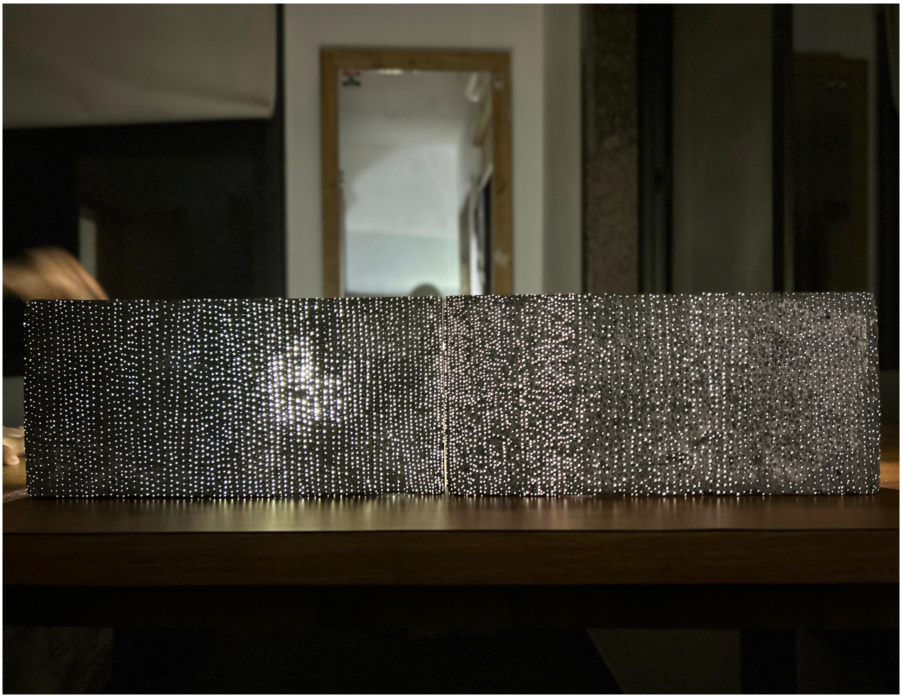

Fig. 3. Illuminated OFDC panel showing the light-transmitting property under controlled lighting conditions.

7 Results

7.1 Product Developments and Innovation

In this study, different sample products made from Optical Fiber Decorative Concrete (OFDC) were created, such as wash basins, tabletops, and wall panels. The molds were specially designed to keep the fibers evenly placed and to achieve smooth surface finishes. The results showed that OFDC can be easily produced and used as a creative material for both building design and commercial purposes.

7.2 Architectural and Interior Applications

OFDC was tested in practical applications like façade panels, floor tiles, and decorative branding pieces. The light-transmitting fibers gave these structures a glowing appearance, which improved the look of both interiors and exteriors. Along with its visual effect, the material also helped in making better use of natural light, reducing the need for artificial lighting during the day.

7.3 Performance Evaluation and Testing

Tests on OFDC showed that it has enough compressive strength for decorative and non-structural uses. Light transmission experiments proved that panels with a higher amount of fiber allowed more light to pass through. This means the transparency of the concrete increases as fiber content increases. These findings suggest that OFDC is a good option for creative, decorative, and energy-saving building designs.

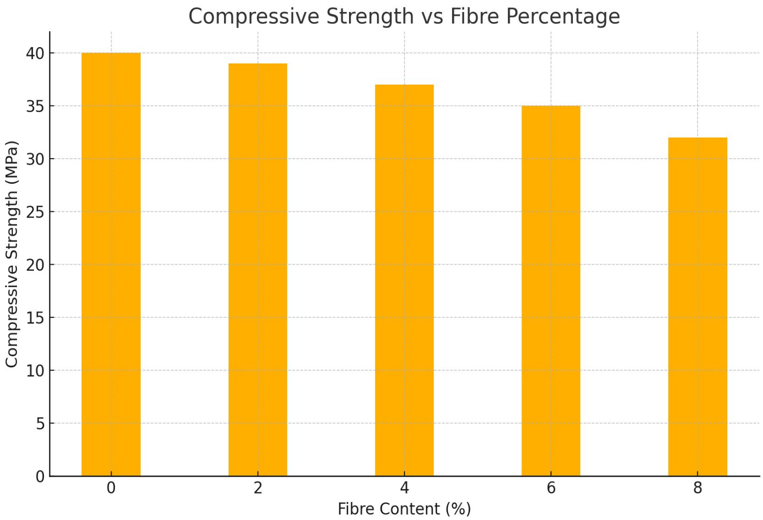

Fig. 4. Variation of compressive strength of Optical Fiber Decorative Concrete (OFDC) with different fiber content percentages. The results show a gradual reduction in compressive strength as fiber volume increases from 0% to 8%.

The compressive strength decreases as fiber content increases from 0% to 8%. The control mix (0% fiber) recorded the highest strength of about 40 MPa. At 4–6% fiber content, the strength remains within acceptable limits while providing good light transmission. Beyond 6%, the strength reduction is significant due to fiber interference in the cement matrix.

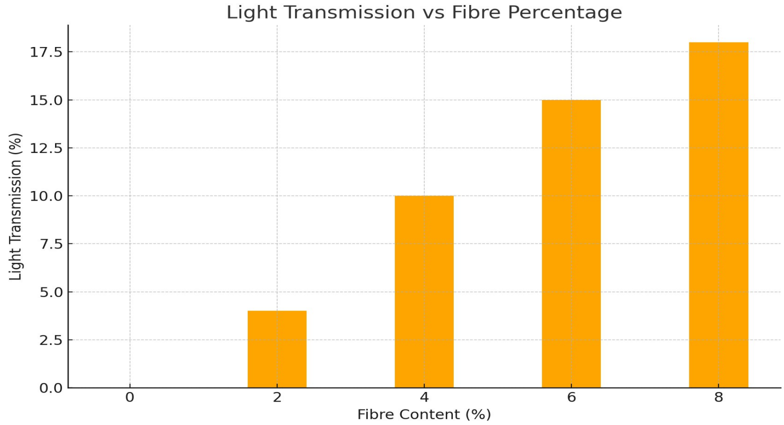

Fig. 5. Light transmission variation of Optical Fiber Decorative Concrete (OFDC) with fiber percentage.

Light transmission increases steadily with the rise in fiber content from 2% to 8%. At 2% fiber, only about 4% transmission is observed, while at 8% fiber, it reaches nearly 18%. This shows that higher fiber volumes significantly enhance transparency in the concrete panels. However, very high fiber content may compromise strength, so an optimum balance is required.

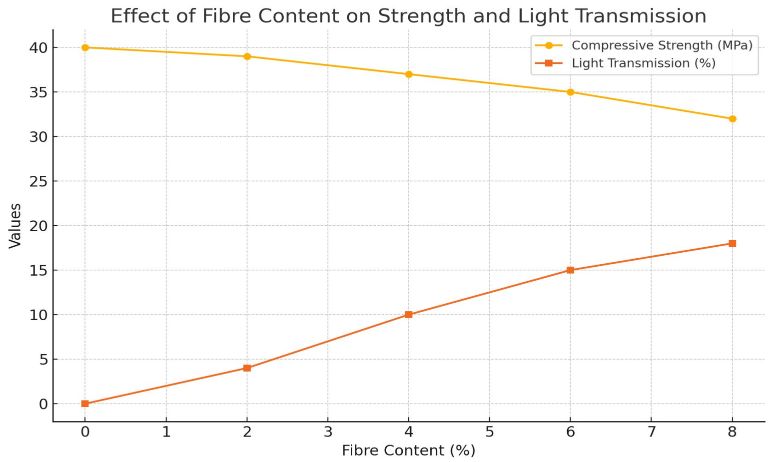

Fig. 6. Effect of fiber content on compressive strength and light transmission of Optical Fiber Decorative Concrete (OFDC).

As fiber content increases, compressive strength gradually decreases while light transmission improves. The optimum balance is observed around 4–6% fiber content, where strength remains acceptable and transparency is significantly enhanced.

7.4 Economic & Sustainability Analysis

To validate the sustainability benefits of Optical Fiber Decorative Concrete, an economic comparison was carried out between conventional concrete and OFDC panels. The analysis considers material cost, energy savings, and long-term financial benefits

7.5 Material Cost Comparison

A 234 mm × 110mm × 40 mm panel was taken as the reference.

Table 1. Material Cost Comparison: Normal Concrete vs. Optical Fiber Decorative concrete panel.

Component	**Normal Concrete Panel**	**OFDC Panel (4–6% Fiber)**
Cement, Sand & Aggregates	₹42	₹42
Optical Fibers	-	₹18 -25
Labor for Casting	₹5	₹10
Labor for Alignment	₹5	₹10
Total Estimated Cost / Panel	₹52	₹80 - 85

The initial cost of OFDC is approximately 35–40% higher due to fiber material and labor.

7.6 Energy-Saving Potential

Light transmission tests in the study showed 12–18% natural daylight improvement. For a room requiring 600 W lighting load, OFDC panels can reduce daily usage by ~15%.

Example calculation:

Normal building lighting: 600 W × 10 h/day = 6 kWh/day

With OFDC: approx. 15% reduction = 0.9 kWh/day saved

Annual savings:

0.9 × 365 ≈ 328.5 kWh/year

At ₹8/kWh → ₹2,628 saved per year (per façade/wall installation)

7.7 Payback Period

If façade installation uses 200 panels:

Extra cost = 200 panels × ₹33 = ₹6,600

Annual savings ≈ ₹2,628

Payback ≈ 2.5 years.

7.8 Sustainability Impact

Reduces artificial lighting requirement by 15–20%

Saves approx. 300–350 kWh electricity per year

Lower carbon emissions: approx. 0.26 tons CO_2 saved annually (Indian grid average 0.8 kg CO_2/kWh)

"Based On Indian electricity grid emission factor"

The energy-saving and payback analysis presented in this study is indicative in nature and based on laboratory daylight transmission measurements, assuming standard indoor lighting conditions.

8 Conclusions

This experimental investigation confirms that Optical Fiber Concrete can provide both good strength and the ability to pass natural light, making it a useful and modern material for sustainable construction and product design.

Concrete panels with 4–6% fiber content were found to give the best results, maintaining strength while allowing enough light to pass through. These panels can help reduce the need for artificial lighting by around 15–20%.

Apart from panels, OFDC can also be used for making various products such as furniture, interior décor items, sanitary fittings, flooring, pavements, art pieces, and urban furniture like countertops, basins, platforms, desks, tables, wall panels, and nameplates. It is also suitable for architectural façades and decorative structures.

The combination of beauty and energy-saving ability makes OFDC a promising material for modern, eco-friendly, and sustainable buildings.

"In addition to performance benefits, OFDC demonstrates measurable economic and environmental advantages. A cost–benefit analysis shows that although initial material cost increases by 35–40%, the reduction in lighting energy (15–20%) results in a payback period of approximately 2–3 years for façade applications. These findings strengthen the sustainability claim and support the practical feasibility of adopting OFDC in urban infrastructure."

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