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Journal of Building Material Science

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REVIEW

Light Transmitting Concrete: A State-of-the-Art Review on Performance and Potential

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ABSTRACT

The use of artificial lighting, particularly in urban areas, contributes to global warming and carbon footprints. Urban expansion is unregulated and unplanned in emerging nations. In the case of India, the urban community is the major consumer of electric power. The invention of Light-transmitting concrete (LTC) lets light pass through opaque concrete and lowers the energy needed for the structures to use. LTC is a sustainable construction material incorporating basic ingredients of concrete in addition to a light-transmitting material such as optical fibre, resin, and glass. The present study investigated the application of light transmission materials like optical fibre, glass wastes, resin, etc., in the concrete. The previous studies have examined the various characteristics of light transmitting concrete, including mechanical properties, light transmittance, energy saving, etc. This article covered the several uses of light transmitting concrete as well as the performance comparison of various other types of materials employed for light transmittance characteristics. It was found that the plastic optical fibre at 1.25% had the highest compressive strength of LTC. The light transmission and thermal insulation properties of resin translucent cement mortar increase interior temperatures by approximately 3°C, resulting in a 20% reduction in discomfort time and a similar decrease in overall energy consumption. LTC was found to be a sustainable solution for the problem of electricity consumption for artificial lighting in residential as well as commercial spaces. Results show that the addition of optical fibre up to a certain percentage in LTC improved compressive strength and light transmittance characteristics.

Keywords: Concrete; Energy Saving; Light Transmitting Materials; Light Transmittance; Mechanical Properties; Sustainable Construction

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ARTICLE INFO

Received: 17 April 2025 | Revised: 11 May 2025 | Accepted: 19 May 2025 | Published Online: 6 June 2025

DOI: https://doi.org/10.30564/jbms.v7i2.9578

CITATION

Sharma, K., Devi, K., Saini, N., 2025. Light Transmitting Concrete: A State-of-the-Art Review on Performance and Potential. Journal of Building Material Science. 7(2): 80–96. DOI: https://doi.org/10.30564/jbms.v7i2.9578

1. Introduction

The construction industry is among the largest industries worldwide and is experiencing swift transformations. Addressing climate change, conservation, and sustainability has initiated a novel trajectory in material production. Concrete is among the most critical components for the construction industry. Every year, billions of cubic metres are produced. Many factors contribute to this trend in concrete use, including its fire resistance, durability, and capacity to withstand mechanical loads. The raw ingredients required to produce concrete are also easily accessible and reasonably priced in comparison to other kinds of building materials and systems [1–4]. The path to advancement and development without endangering the environment and preserving natural resources for future generations is through sustainable development. According to the United Nations Environment Programme report in 2013, the consumption of power for lighting was responsible for roughly 20% of worldwide electricity demand and 6% of CO_2 emissions [5]. One of the sustainable building materials that would reduce power consumption for lighting without compromising structural strength is light-transmitting concrete. As per the case study of the office building in Jordan, electricity consumption can be reduced by 26% by the use of LTC on an average day of December [6]. Lighting accounts for a major 19% of all world electrical use [1]. Many problems connected to climate change, economic development, and increasing energy prices are affected by the great amount of electricity required for illumination. For instance, high-rise structures have notable lighting needs even during daylight hours [1]. The requirement for artificial lighting is growing quickly due to urbanisation, which also boosts building energy consumption and increases global warming. This problem must be solved by giving top priority to material and architectural approaches that maximise the use of natural light, which will lessen reliance on artificial sources and promote human well-being. Conventional techniques allow natural light in by using materials like glass bricks, toughened glass, or transparent polymers. However, these materials frequently offer insufficient thermal insulation and are unable to control the intensity of direct sunlight. The use of these materials lowers their potential for energy savings and raises energy consumption for air conditioning due to their poor insulating characteristics. Additionally, these are inadequate to resist the effects of impact and wind load. A viable solution for this scenario is the development of a novel type of concrete, i.e., light-transmitting concrete. In contrast to pure transparent materials, LTC modifies the functional components of light-transmitting materials and improves control over sunlight in various areas. In addition, concrete has stronger insulating qualities than glass or plastic and is more resilient to impacts and wind. Additionally, LTC finds use in infrastructure components like stairwells, speed bumps, walkways, road markings, and tunnels. LTC remains inadequately recognised and utilised in the construction sector as an eco-friendly building material may be attributable to several reasons such as high labour expenses, sophisticated manufacturing processes, insufficient accurate data regarding the mechanical qualities and durability to assess its service life [7].

Several materials were employed to obtain the light transmissibility in concrete without sacrificing its strength; Hungarian architect Aron Losonczi, however, built a concrete block with light-transmitting qualities using optical fibre and created LiTraCon [8,9]. Comprising optical fibres and fine concrete, the material produced both internal and external uniformity. Produced in blocks, it was largely used for ornamental reasons. Using almost 4,000 TC bricks, Italy built its pavilion at the World Expo 2010 in Shanghai, China. The blocks were too hefty for use as a façade sub-system in buildings. Another product highlighted was Pixel Panels, developed by Bill Price of the University of Houston, plastic fibres arranged in a grid. These panels glowed in a pattern evocative of hundreds of tiny stars in the nocturnal sky. The University of Detroit Mercy has also found a way to produce translucent panels made of Portland cement and sand, strengthened with a small amount of chopped fiberglass. Measuring only 2.5 mm in thickness at their centres, the panels were thin enough to show translucence under direct illumination. Historically, TC technology's main focus has been on its visual appeal and its use in artistic design [10]. Initial efforts to create clear concrete included inserting glass plates inside blocks. Efforts since then have been to utilise glass as the transmission medium of light in concrete. To obtain translucence, researchers sliced the moulded sample into thin panels and mixed discarded glass into concrete using the conventional mixing technique. Translucent panels made from discarded glass with an acrylic solution were then buried in concrete. The material showed reasonable light transmittance [11].

LTC is made from two fundamental materials: fine concrete and light-transmitting substance. Fine concrete is formed of cement, fine aggregate, and water; whereas various materials, including optical fibre, glass, and plastic fibre, can be included to produce LTC. Usually, the application of optical fibre in concrete results in LTC; it consists of three parts: core, cladding, and coating. The glass core centre lets the light travel; the cladding surrounds the core and reflects the light into it. The covering protects the fibre from harm and dampness. In LTC, optical fibre makes up 2% to 6% of the concrete volume. Fibres arranged in rows are 5 mm to 10 mm apart [1]. Optical fibre is a closed fibreglass tube that can carry light signals at the speed of light over great distances. Various sectors use fibre optics, including laser technologies, decorative arts, medical, and communication. The fundamental characteristic of the fibre is that, regardless of its arrangement or the number of bends and directional changes, it does not dissipate any energy provided to one of its ends. The energy entering one end is equivalent to the energy exiting the opposite end. In the production of translucent concrete, no translucent polymers or glass can effectively compete with the fibre, as they dissipate light energy at every curvature and bend. Fibre optics demonstrated unparalleled quality. Nonetheless, the price has proven this material. It is perplexing that, in telecommunications, the use of costly materials poses no issue, yet the development of Litracon encounters challenges. The expense of incorporating fibre optics in comprehensive communication installations is negligible, while the overall installation costs are substantial; thus, the addition of optical fibre does not significantly elevate expenses while markedly enhancing installation efficiency. Nevertheless, in construction materials, the amalgamation of inexpensive concrete with costly fibre significantly escalates the price many times [12].

LTC may also be used for wall or floor portions requiring light transmission in buildings or other structures. Currently, the LTC panels are unsuitable for the use of reinforcements since they alter the arrangement of optical fibres inside the concrete. Therefore, the manufacturing of LTC panels without reinforcements must aim for both high light transmission and high strength. Moreover, to improve the light transmission of concrete, it is necessary to create LTC with more fibre content than earlier studies, therefore increasing the application of this material. Consequently, achieving both excellent light transmission and substantial strength is crucial for the development of LTC panels devoid of reinforcements, with the design of the concrete mixture proportions being pivotal. The water/binder mass ratio must be decreased to provide adequate concrete strength and sufficient workability of fresh concrete to effectively compact the extremely thin spaces between the optical fibres in a configuration with a higher content layout. Alongside the aforementioned technological hurdles, the utilisation of eco-friendly raw materials in the production of LTC, a material that mitigates environmental repercussions, should also be taken into account. Nevertheless, its extensive application in LTC manufacturing has not been comprehensively examined in prior research. Furthermore, as LTC predominantly operates in areas illuminated by artificial light or sunlight, the polymer optical fibres exposed to elevated temperatures may undergo deformation, hence potentially impairing the light transmission capability of LTC. Consequently, it is vital to examine the early effects of elevated temperatures, optical fibre configuration, and light source on the light transmission capacity of LTC to enhance the database for future lighting design calculations [13–15].

The light-transmitting concrete was developed using the conventional mortar matrix and optical fibre to transmit the light and illuminate the interior area. In the present study, the different transmitting materials such as optical fibre, glass waste, resin etc, have been reviewed in the light transmitting concrete. The mechanical properties, especially compressive strength and flexural strength, and light transmittance characteristics, in the light-transmitting concrete were studied. The research study aimed to present a critical review of the different uses of light-transmitting materials in concrete to study their effect on the strength, durability, light transmittance, and energy saving. The application and limitation of the light-transmitting concrete were also studied in this work. The development of light-transmitting concrete was also highlighted. The future scope or the gap was also highlighted in this paper.

2. Materials

To develop the light-transmitting concrete, different transmitting materials were used in the different studies. The production of light-transmitting concrete involves the incorporation of a transmitting material into a matrix of concrete that is closely organised. Glass fibres, plastic optical fibres, embedded glass panels, piezoelectric substances, and photosensitive materials are all examples of different types of material. In the limited study that has been done, the focus has been on different types of materials and how effective they are at facilitating light transmission. Materials that transmit light make it easier for the entire light spectrum to pass through them, which in turn makes it possible for infrared rays from the sun to get through without being blocked [11]. The materials, such as optical fibre (plastic, glass), glass waste, and resin, are the commonly used materials reviewed in this study.

The global optical fibre monitoring market is projected to be valued at USD 731.5 million in 2025 and is anticipated to reach USD 1,982.9 million by 2032, reflecting a compound annual growth rate (CAGR) of 15.3% over the period from 2025 to 2032. Annually, thousands of tons of waste glass are dispatched to landfills without adequate reutilization. Victoria generates around 257,000 tonnes of glass waste annually. Of this amount, 195,000 tonnes (76%) is collected, while 124,000 tonnes (48%) is recycled into glass; the remaining 52% of glass fines is redirected to storage. Additionally, the global market produces 130 million tonnes (Mt) of glass per year. The global volume of recycled glass is estimated at approximately 27 million tons, comprising merely 21% of the yearly glass production [16]. The report published by Skil Global indicates that the recycled plastic resin industry exhibits a Compound Annual Growth Rate (CAGR) of 9.01%. The market for recycled resin goods is expanding due to its beneficial environmental effects. Reusing and recycling scrap resin diminishes trash generation, conserves energy resources, and substantially cuts greenhouse gas emissions [16].

2.1. Optical Fibre

The basic theory behind the workings of optical fibres is the concept of total internal reflection. When light travels from one medium to another, a phenomenon known as refraction takes place. The angle at which light is refracted is determined by the refractive indices of the two different media. It is possible to efficiently demonstrate the relationship between the angle of light and the refractive index by the use of Snell's law of refraction. When the angle of incidence is greater than the critical angle, light is reflected back into the medium that it was impacted upon. This is the fundamental principle that underpins the construction of optical fibre connections. To ensure comprehensive internal reflection with minimal loss, the medium has been selected. Fibres in concrete need to be aligned with the direction in which light is incident for the material to be able to transmit light. The ductility of optical fibres makes it possible for them to be oriented in any direction that is desired; however, bending the fibres will invariably result in a slight increase in losses. The fibres have the extraordinary ability to transmit light information from the brighter side to the darker side while maintaining accurate colour fidelity [11,17]. This is the trait that makes the fibres notable. Optical fibre is the material that is extensively employed in LTC for light transmissibility in concrete. An optical fibre is constituted of three major elements, as shown in **Figure 1**, given below

- Core
- Cladding
- Coating

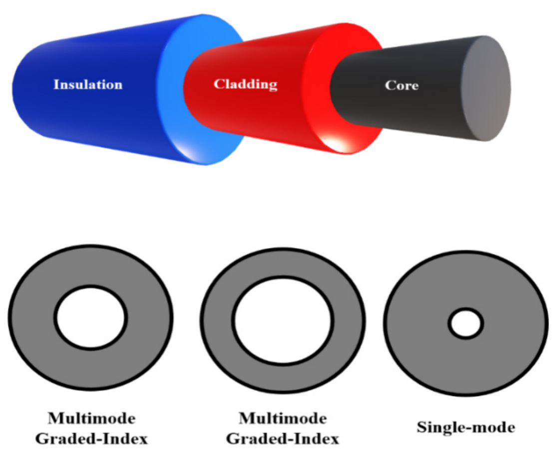

Figure 1. Layers and types of Optical Fibre [12].

One of the most important components of the fibre is the core, which is the interior of the fibre and is responsible for transmitting all of the data from the transmitter to the receiver. The diameter of this component ranges from 5 to 100 microns, which is relatively small. Cladding refers to the substance that surrounds the core layer. As a result of its diminished capacity to reflect light, the light is maintained within the core and can freely travel over the whole length of the link. A buffer layer and a plastic rubber sheath are used to protect the fibre from being damaged by mechanical forces. The total thickness of the fibre falls within the range of 250 to 300 microns [12]. It is possible to classify optical fibres according to the following criteria: (1) dimensions, categorising them as either single-mode or multimode; (2) refractive index profiles, classifying them as either step index or gradient index fibres; and (3) material, classifying them as either polymer optical fibres (POFs) or silicon optical fibres (SOFs). Within the field of optics, the refractive index is an essential statistic that provides information on the speed at which light travels through a specific medium. To ensure that light is directed into the core of the fibre effectively, the core, which has a refractive index value of n_c, is surrounded by cladding that has a higher refractive index value of n_{cl}. As the radius of the core rises with the wavelength at which it operates, the core is able to handle a greater number of propagation modes. This allows for the classification of fibres into single-mode and multimode categories. Since multimode fibres have a far higher light capacity than single-mode fibres, it is possible that the light can be directed into the core of the fibre with greater ease. Because of the presence of a large number of modes, the quality of the light beam that is released by the fibre is negatively impacted. Dispersion is a process that occurs over time as a result of the varied speeds at which light travels through different materials. This phenomenon is referred to as dispersion. In multimode fibres, the refractive index profile of the core can be engineered to gradually decrease from the centre to the periphery, causing light to bend along its transmission trajectory. This is done in order to prevent dispersion since it causes light to bend along its transmission trajectory [18,19]. For light transmissibility, a major parameter is the refractive index. The refractive index of optical fibre depends on different classes of fibre, that is single-mode and multimode. The Numerical Aperture (NA) of an optical fibre represents the sine of the maximum angle at which light can enter the fibre and still be guided through total internal reflection. The value of NA varies among different optical fibres. A higher refractive index contrast between the core and cladding (i.e., larger n1n1 relative to n2n2) results in a higher NA, enabling the fibre to accept light at wider angles. However, increasing the NA also typically requires a higher dopant concentration in the core, which can lead to greater scattering losses. The attenuation of an optical fibre refers to the loss of light intensity per unit length as it travels through the fibre. It is a crucial performance parameter and is typically measured in decibels per kilometer (dB/km). Attenuation varies with wavelength and affects the efficiency of signal transmission [19].

Optical fibre is the most common and often used light-transmitting component in the production of LTC due to its better light transmittance qualities. Usually, optical fibre consists of two materials: glass or plastic. Optical fibre had been widely used as sensors in structural health monitoring before LTC was included with optical fibre because of its great sensitivity, non-destructive evaluation, low cost, multiplexing capabilities, and ability for internal embedding inside concrete [7]. Optical fibre sensors embedded in concrete may track strain and identify vibration, corrosion, and deformation. Below is a list of several materials utilised for the optical fibre [20].

a). Glass Optical Fibre (GOF):

The light transmittance property of LTC incorporating GOF is due to the phenomenon called total internal reflection. GOF performs well under difficult circumstances, like a higher range of incident angles. It can transmit light up to 60^{o}.

b). Plastic Optical Fibre (POF):

POF is manufactured from polymers. Light transmissibility of POF is comparable to GOF, as illumination happens through its core.

2.2. Glass Waste

It has been observed that a certain million tons of waste glass is collected from different sources of its generation due to the combined effect of rapid development and industrialisation. The prime sources of this waste are food containers, bottles, glasses used in windows, and glasses for electrical equipment. LTC is usually made by combining coarse waste glass with cementitious material. Provided both ends of the waste glass are near the surface of the concrete panel, light may penetrate the LTC-contained translucent waste glass. Waste glass's discontinuity limits the thickness of LTC panels to maximise light transmission efficiency. Using waste glass in LTC raises another issue: the alkali-silica reaction (ASR). ASR is a damaging process in concrete whereby the alkaline pore solution reacts with metastable silica from aggregates, hence generating ASR gel that expands and causes cracking in the concrete. Mineral admixtures such as metakaolin, ground-granulated blast-furnace slag (GGBS), silica fume, or fly ash are added into the mix design to reduce or eliminate the formation of ASR gel in LTC [7,21]. Glass waste is used in two mentioned ways in LTC.

a). Glass waste as fine aggregate:

Waste glass bottle was used after crushing and sieving through 2.56 microns to be used as fine aggregate. Through this process, glass waste can be used partially in place of sand.

b). Glass Waste as coarse aggregate:

To create LTC, coarse waste glass is often combined with self-compacting concrete. When both ends of the waste glass are at the surface of the concrete panel, light can pass through the LTC-contained translucent waste glass.

2.3. Resin

A translucent material, polymer resin, has been used in LTC since 2011 [7]. The study of the mechanical properties and light transmission of LTC included several polymer resins, including epoxy resin, polyester resin, and polymethyl methacrylate (PMMA) resin. For manpower expenses and material weight, polymer resin is a better selection than glass and optical fibre. Regarding light translucency, it is similar to optical fibre and glass; however, with a high-angle incoming light source, translucency decreases. The casting process of LTC greatly affects its compressive strength since it influences the resin-to-matrix interface adhesion and bonding [4]. Including resin to increase the structural integrity of light-transmitting concrete (LTC) will help to enhance its light transmission characteristics. Resin Translucent Concrete (RTMC) offers benefits such as better thermal performance and light transmittance when compared to traditional LTC using optical fibres. Transparent polymer resins help to manufacture light-transmitting concrete. Used in buildings as components of composite materials and adhesives, these resins are quite common. Among the many different kinds of resins accessible are acrylic resin and epoxy resin. Concrete made only of tiny particles can create a concrete matrix. The layered assembly technique of the compound can build a light-transmitting component, generating continuous layers that operate effectively inside the material. The utilisation of contemporary colours and admixtures may enable the manufacturing of concrete with a significant decorative impression. This may address the challenge of the complex manufacturing process, but it will not reduce material costs [4,22,23].

3. Preparation and Development of LTC

The development of LTC is an innovation that is achieved through the implementation of new materials and construction methods to create a unique product that can transmit light while maintaining the strength and durability of conventional concrete. **Figure 2** shows the process involves several key steps involving the selection of suitable proportions of mortar/concrete mix, casting and testing of specimens for light transmitting concrete. The manufacturing of light-transmitting concrete, sometimes referred to as smart transparent concrete needs two basic components: one from the sensing field and the other from the construction industry. A sensing and optical transmission medium is an optical fibre. The manufacturing method of the traditional clear concrete block can be outlined as follows: Initially, in line with the volume ratio of POF and concrete, orthogonal arrays of holes are drilled into the plastic sheet (**Figure 2**). POFs are then pushed through the holes of two plastic sheets attached to the slots of wooden formwork; a specified concrete mix is then poured into the formwork and fully vibrated on the table [18].

In the development of LTC, the first and foremost step concerns the selection of the raw materials for the concrete or mortar mix of desired strength and light transmittance characteristics. The plastic optical fiber, glass optical fiber, glass waste, and resin have been used as light transmitting materials. The selection of material depends on the properties of the desired light, the cost requirement, and the ease of integration with the concrete matrix. Optical fibres are the most popular due to their efficiency in light transmission, but the researchers also used glass waste or resin, which depends on where it is used. The designated mix should consist of an accurate ratio of cement, aggregates, water, and light-transmitting materials for the desired strength and light transparency. The final step includes both the preparation of the moulds and casting of specimens of LTC followed by testing. The moulds are to be prepared in such a way that the LTC mixes consisting of various light-transmitting materials can be uniformly and homogenously poured and compacted in them. The specimens are then taken out of the mould, followed by curing for a specific duration and testing [14].

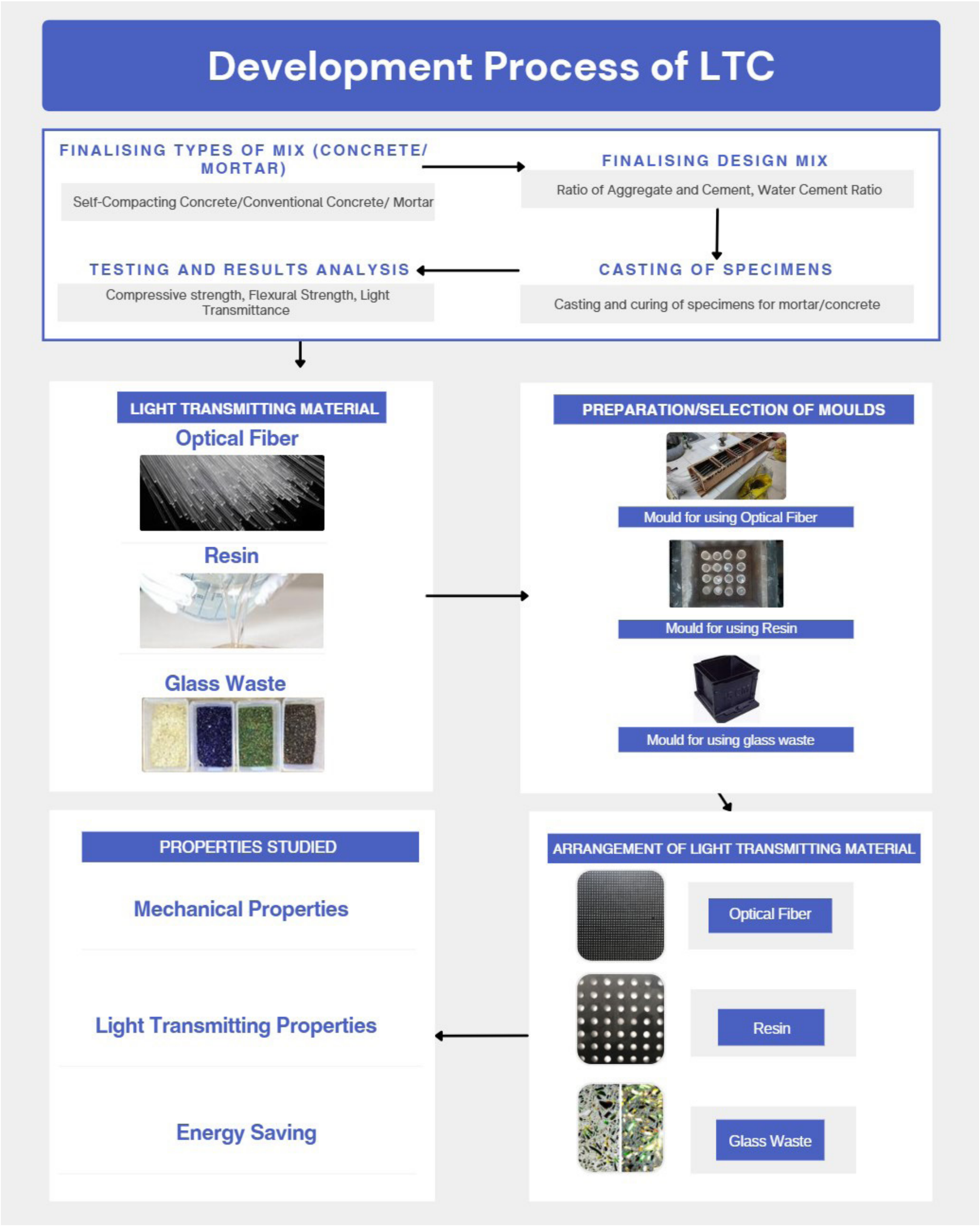

Figure 2. Development Process of LTC.

4. Properties

The different properties of LTC containing the various light transmitting materials, such as mechanical properties, i.e., compressive strength, flexural strength, light transmitting concrete, and energy saving, were reviewed in the present study.

4.1. Mechanical Properties

The mechanical properties of concrete play a crucial role in concrete because it describes performance and structural reliability for various applications. The primary properties such as compressive strength, tensile strength, flexural resistance, and elasticity. Compressive strength defines the axial resistance of the material, which must bear axial loads, and it is important for columns and foundations. The tensile and flexural strengths indicate the capacity of the material to withstand bending stresses and tensile forces. It maximises the structural integrity of the concrete element and minimises cracking [24,25]. The present work examines the mechanical characteristics of light-transmitting concrete, including compressive strength and flexural strength, and illustrates these properties in **Figures 3** and **4**, respectively. It has been observed from the previous studies that the mechanical characteristics, i.e., compressive strength and flexural strength of LTC are much dependent on volume fraction, diameter, and spacing of light transmitting materials. Various techniques were used in the preparation of light-transmitting specimens, such as variation in size, shape, and volume of fibres, different light-transmitting materials, uniform and random distribution of fibres, etc.

The addition of optical fibre in self-compacting concrete increased the compressive and flexural strength of the light transmitting concrete. POF at 1.25% had the maximum compressive strength of 44.2 N/mm^2 [26]. The strength of LTC increased with the increase in the percentage of optical fibre [1]**.** The use of 4% or 5% optical fibres boosts the compressive strength of LTC. The compressive strength is proportional to the diameter of the perforations of the mould and the optical fibre dimension [27]. The diameter of fibre also influenced the compressive strength of LTC, as the 2mm diameter of optical fibre has higher strength compared to 1mm diameter [9]. However, some studies concluded that an optical fibre of 1mm diameter increased the strength of concrete; afterwards, it reduced the strength of LTC [7]. The incorporation of ground granulated blast furnace slag and Fly Ash in LTC achieved a compressive strength of 100MPa and flexural strength of 17.5 MPa [14]. The compressive and flexural behaviour of LTC was comparable to conventional concrete and can be used for structural applications [18,27,28]. The compressive strength increases with the addition of POF ratios due to the perpendicular orientation of the loading machine relative to the POF arrangement at consistent spacing within the cubic specimens. Additionally, the increase in contact area resulting from the greater number of POFs in fixed holes within the specimens further enhances the concrete structure's strength [18].

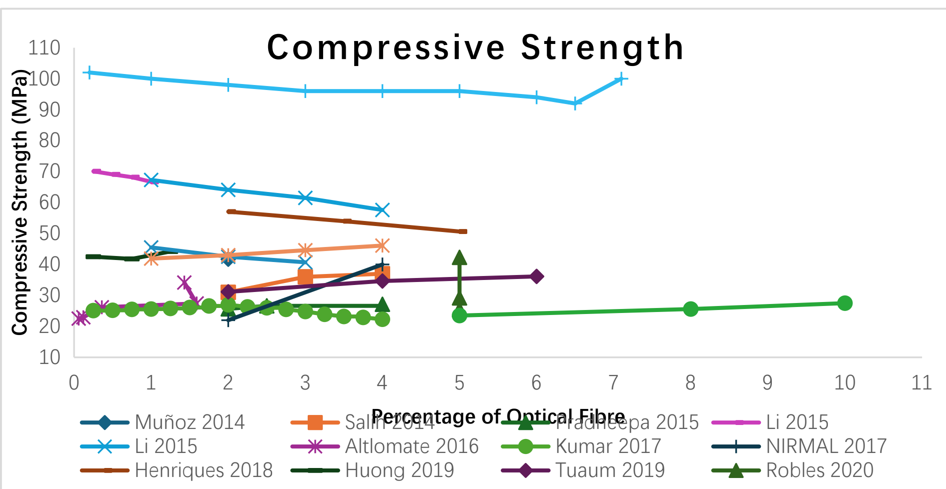

Figure 3. Variation of Compressive Strength wrt Percentage of Optical Fibre.

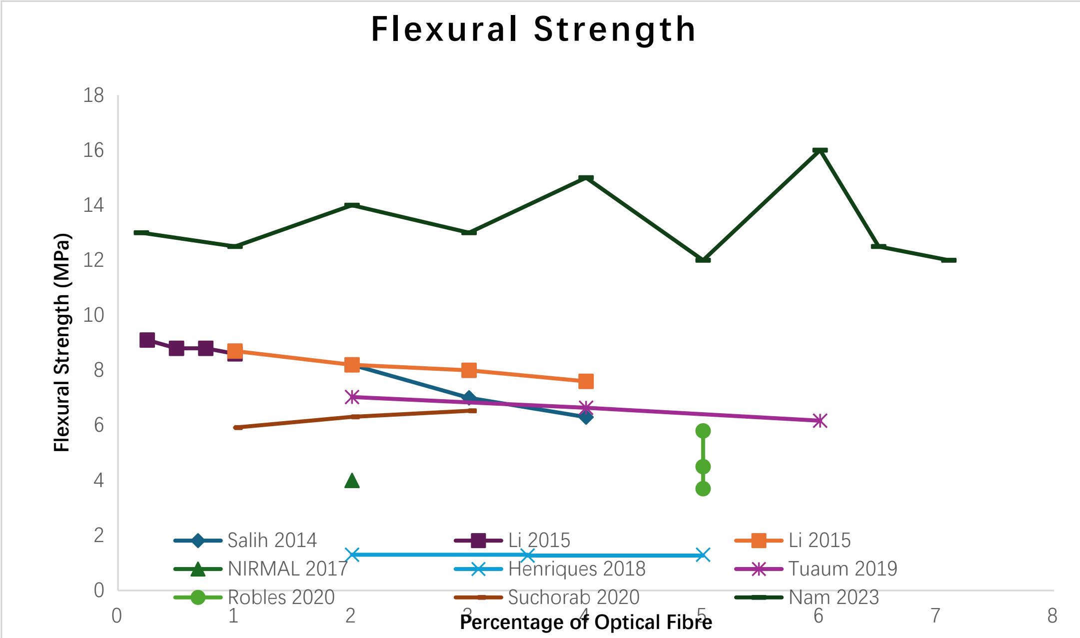

Figure 4. Variation of Flexural Strength wrt Percentage of Optical Fibre.

The influence of plastic optical fibre, ribbed resin rods, and a composite based on tempered glass waste and epoxy resin on the properties of concrete was studied. Results showed that the use of POF and resin rods had an acceptable compressive strength considering structural performance, whereas the use of POF enhanced the tensile strength of concrete [29]. The effect of the diameter and spacing of optical fibre made of polymethylmethacrylate (PMMA) in the light-transmitting concrete was investigated. The highest compressive strength was observed in LTC with a fibre diameter of 1.0 mm. The compressive strength of the concrete was diminished with decreased fiber spacing. The UPV results indicated that all specimens were of high quality, irrespective of the optical fiber's inclusion. The microstructure analysis revealed that the fibre-matrix interface of all LTC specimens was devoid of visible spaces, except for LTC with a 1.5 mm fiber diameter [30]. Shenoy et al., 2025 developed the light-transmitting concrete using bundled fibres placed in the grid of even spacing was developped [31]. It was found that the four-strand bundles of 1mm diameter fibre placed at a spacing of 12 mm had the optimum mix with satisfactory strength characteristics [31]. Singh et al. 2025 examined the impact of plastic optical fiber integration on the compressive strength of concrete. The compressive strength analysis confirms that the strength is reduced by POF incorporation, particularly at smaller fiber spacings, as a result of weak interfaces and void formation. However, the reduction of strength loss is achieved by increasing the fiber spacing to 20 mm, which suggests that this configuration is more suitable for practical applications [32].

Kumar et al. (2024) investigated the feasibility of using glass fibres as an alternative to optical fibres and partially replacing fine aggregates with glass powder, with a focus on evaluating the mechanical properties of the resulting composite. In this study, glass rods were embedded in the concrete matrix at a spacing of 1.67 cm, and the specimens were tested for both strength characteristics and light transmittance. The findings indicated that the incorporation of glass fibres did not compromise the mechanical performance when compared to conventional mortar [33]. Sangeetha et al. (2022) investigated the properties of LTC incorporating plastic optical fibres (POF) with diameters of 0.5 mm, 0.75 mm, 1 mm, and 2 mm, arranged at different spacings (10 mm and 20 mm) [34]. The experimental results revealed that the inclusion of optical fibres did not reduce the compressive strength of the concrete specimens. On the contrary, a significant improvement in 28-day compressive strength was observed. This enhancement in strength was attributed to the addition of fibres and improved bonding between the fibres and the concrete matrix. However, it was noted that specimens with smaller-diameter fibres (e.g., 0.5 mm) exhibited lower compressive strength, due to the higher fibre volume ratio, which may negatively influence the concrete matrix. Based on light transmission test results, the study concluded that the optimal configuration for maximum illumination was achieved with 2 mm diameter POF at 10 mm spacing, making it suitable for the production of light-transmitting concrete [34].

The addition of light-transmitting materials decreased its compressive and flexural strength. The reduction in strength due to the addition of optical fibre may be because of the smooth surface and hydrophobic nature of optical fibres, resulting in poor adherence to the concrete matrix [35]. The inclusion of plastic optical fibre increased the porosity, which contributes to the reduction in compressive strength and durability [36]. Some researchers concluded that the compressive strength of the LTC or Light Transmitting Cement-based Material reduced with the increase in the amount of POF [37–39]. Saleem et al., 2017 reported that the compressive strength of concrete with plastic optical fibre (32.61MPa) as tendons was less than that of concrete without plastic optical fibre (36.71MPa) [40].

Saleem and Blaisi, 2019 developed Glow-in-the-dark concrete of average strength of 49.47 MPa and yielded an average compressive strength of 45.48 MPa in the case of GiD-modified specimens [41]. Shen & Zhou, 2020 investigated that the resin material, RTCM, and plain concrete had respective thermal conductivities of 0.16, 0.382, and 0.894 W/(m.K) [42]. The material made of resin exhibited the lowest thermal conductivity among all. This demonstrated that RTCM could more successfully inhibit heat transfer and had superior thermal insulation performance. The compressive strength of RTMC declined with a rise in resin percentage. When the area ratio was within 5%, the strength was comparable to that of normal concrete [43].

4.2. Light Transmitting Properties

The light-transmitting property of concrete is an ultimate breakthrough in concrete technology, and it integrates functionality with aesthetics. This light-transmitting material, made possible by the inclusion of optical fibres or translucent resins, enables natural or artificial light penetration through its structure, producing extraordinary visual effects without affecting mechanical strength. These properties allow for the significant improvement of the aesthetic properties of architectural applications, such as the design of illuminated facades and partitions, and decorative elements. The transmission properties help to achieve energy efficiency through reduction in artificial lighting, promote sustainability, and lower consumption of energy in contemporary construction. Researchers have predominantly conducted light transmission experiments of LTC across many factors. No guidelines or standards have been created for assessing the light-transmission properties of LTC. The experimental setup and test equipment varied from researcher to researcher. To minimise light dispersion and make certain that all light beams from the source are directed towards the samples, an enclosed zone to evaluate the brightness of the long-term cloud was established. The data that was gathered is unique due to the uncertainties that were produced by the precision and dependability of the measuring devices [18]. This is despite the fact that the variance in measuring instruments might not have a significant impact on the luminance measurements.

The use of renewable energy is seen as a quick way to promote energy savings in buildings and lower carbon emissions. Solar energy is a good renewable energy source for use in building engineering since it has a clean, infinite supply and great availability. Solar heating and natural light are the main and practical ways to capture solar energy in structures. Still, windows usually show poor thermal efficiency since they are the main architectural feature enabling natural light and outside visibility. Comprehensive studies have therefore been done to design energy-efficient building envelopes meant to reduce net energy use for heating, cooling, and artificial lighting. Because of its great adaptability to climatic circumstances, switchable windows have become one of the most attractive glazing systems in both academic and industrial settings in recent years. Representative examples are electrochromic, photochromic, and thermochromic windows, which change their optical characteristics in response to electric current, particular light wavelengths, and temperature, respectively, therefore controlling solar heat gain in a controlled or passive way. Apart from switchable windows, earlier studies have shown that both optical fibres (OFs) and optical fiber-based translucent concrete (OFTC) have dynamic transmission that is greatly affected by the angle of incidence. Defined by the numerical aperture (NA) of the fibre, a certain optical fibre (OF) has a light acceptance cone. A light beam can be transferred over an optical fibre efficiently through complete internal reflection when it enters the light acceptance cone of the fibre. The sun incidence angle during summer is usually higher than in winter when using a south-facing wall north of the Tropic of Cancer (around 23°26' N) as a reference. Therefore, an OFTC wall shows low summer transmittance to minimise solar gain and high winter transmittance to lower heating needs, making it a good building envelope for improving energy efficiency. Since its creation, translucent concrete has attracted great attention because of its appealing lighting qualities, and it has been used in many buildings and infrastructure, including museums, tunnels, road markings, and pavements for illumination or decoration. At the same time, different experiments and numerical simulations have been conducted to investigate the optical and thermal performance, as well as the payback period of translucent concrete combined with several light-transmitting materials, including optical fibres, waste glass, resin, glass rods, and plastic bars. Among the most often used and researched elements in transparent concrete are plastic optical fibres [44]. The light transmission property of LTC is reviewed in this study, and variation in the light transmittance property has been presented in terms of percentages and units of light transmission in **Figures 4** and **5**, respectively.

For evaluating light transmitting properties, various methods have been applied. In some research, natural light was used to assess light transmission through concrete in the case of natural light, it was found that maximum light transmission was from 12:00 Noon to 02:00 P.M., and the peak value was different in different studies [44–47]. Some researchers used artificial light, and in the case of artificial light, peak values were obtained at the nearest tested distance, with an increase in the distance between the light source and the LTC value of light transmission decreases [5,48]. The diameter of the POF does not significantly influence the light transmission through the specimens, indicating that the enhancement in light transmittance is attributable to the increased volumetric ratio of the POF. The highest light intensity was recorded in the specimens at approximately 1 p.m., aligning with peak hours, and these results corroborate earlier investigations. The behaviour of light transmitted through POF in conjunction with translucent self-compacting concrete (TSCC) illustrates that the transmitted light conforms to the principles of optics and is affected by related phenomena. The associated phenomena of light are encapsulated in three categories: reflection, refraction, and total internal reflection. Light sent through photonic crystal fibres experiences two forms of loss: absorption and scattering, which arise from variations in the material's density and composition. This delineates the behaviour of light transmitted by the TSCC, wherein total internal reflection among the POF walls enables the transmission of light that impinges against the surface of the TSCC specimens to the opposing side. Concerning the incident light, which is natural light, a fraction is refracted, while the remainder is reflected. Consequently, a TSCC absorbs a segment of this light while dispersing another segment. This may be evident in the transmission rates of TSCC light and specific aberrations of the Gaussian curve in the graphs (**Figure 6**) [18].

The numerical Aperture of optical fibre, incident angle, light intensity, the diameter and volume of light transmitting material, and distance of the source of light were some factors on which the amount of light passing through LTC was dependent. Various methods were also used in this assessment, as some researchers used simulation through the Ray-Tracing Method [44,47], an artificial neural network model using Bayesian Regularization [46], Radiance material, and Diva [49]. Some Researchers used Light Depended Resistor [50,51], the spectrometer was also used for the optical spectral range [9]. It was found from various studies that light transmission through LTC is sufficient to be used for office buildings, galleries, and museums. More research needs to be done on the light transmission of LTC, as different weather conditions have not been included in any studies, and what will be the impact of dust settling on the fibre surface is not considered.

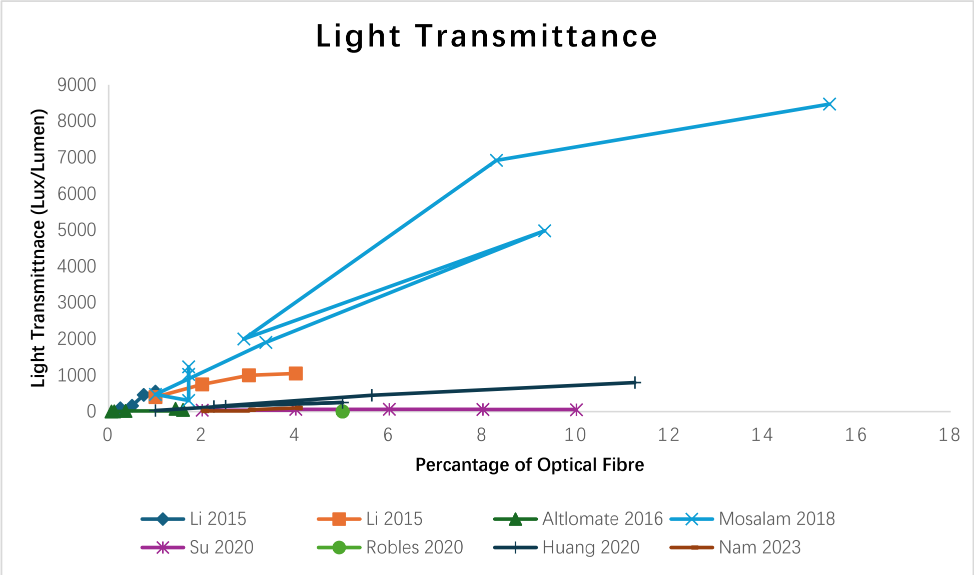

Figure 5. Variation of Light Transmission (Lux/Lumen) with Optical Fibre content.

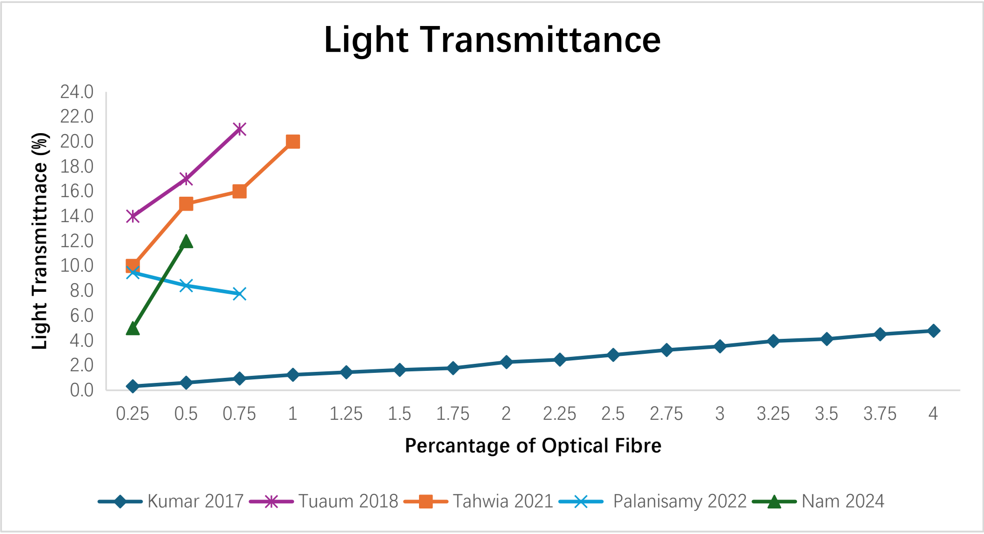

Figure 6. Variation of Light Transmittance in Percentage with Respect to Optical Fibre Content.

4.3. Energy Saving

LTC decreased the requirement of artificial lighting and saved electricity usage, thus saving in energy consumption [42,49]. The use of optical fibre and resin in light-transmitting concrete resulted in lower electricity consumption. Polymethyl methacrylate tubes increased the illumination energy efficiency [8]. High-Performance Light-Transmitting Concrete (HPLTC) can decrease energy usage in workplaces by 45.7% in Tehran, 31.5% in Vancouver, and 38.8% in Phoenix [49]. Using high numerical aperture optical fibres in OFTC can result in up to 9% energy savings [45]. Shen & Zhou, 2020 concluded that simulations with Ecotect software indicate that RTCM products greatly improve interior daylight conditions, which cuts artificial lighting usage from 72% to 41%. RTCM's strong light transmission and thermal insulation raise interior temperatures by almost 3 °C, lowering discomfort time by 20% and total energy usage by around 20% [42]. There is a growing recognition that translucent or light-transmitting concrete is an environmentally friendly material that can reduce energy consumption. This is accomplished by reducing the requirement for artificial lighting during daylight hours and for heating during the winter months. An experimental investigation of the light transmission and thermal properties of a translucent concrete panel was carried out by modelling the orientation of optical fibres within the concrete after it had been exposed to simulated sunlight for a period of one year [18].

5. Applications and Limitations

From the results of mechanical and light transmission evaluation, it is concluded in research that LTC is best suited for offices, galleries, and museums. Translucent concrete panels can also be used for architectural walls, subterranean stations, and structural facades in banks, jails, and museums. Plastic-optical-fibre-based transparent concrete can withstand compressive stresses and improve light transmission, making it suitable for both flexible and stiff pavements. It is also found that LTC is adaptable and can be used in various applications, such as floors, pavements, load-bearing walls, furniture, facades, interior cladding, and partitions. Furthermore, tunnels depend on the high-intensity lighting system to improve visibility and safety. The LTC can be used for the building of tunnels and dimly lighted subway stations since it can shine. Though no more studies on mechanical specs or brightness levels for this application have been done, LTC is used to create a mock-up system for tunnel pergolas. Used as conduits, the solar optical fibre system illuminated the highway tunnel from outside using optical fibres. Optical fibres in LTC can act as light pipes, creating tunnels that carry light into them, hence improving the internal lighting system. LTC panels were used to build the partitions and walls of LTC in the Bank of Georgia, the transparent facades at Aachen University in Germany, and the Al Aziz Mosque in Abu Dhabi. A German company, called "Lucem Lichbeton", has led the way in LTC pathways and pavements. Renowned for its cube-shaped transparent ceiling, which lets natural light shine the inside, the freshly constructed "Stuttgart City Library" in Germany The artwork installation called "European Gate", built in 2004 in Hungary honouring Hungary's membership to the European Union (EU), is the most important work showing the LTC idea. It is located next to the public entrance to "Fortress Monostor" in the town of Komárom, Hungary. Its integration of visual illumination shows makes it an extraordinarily remarkable and unusual masterpiece. The LTC blocks of this road mimic concrete pavement all day and night [18].

Despite several advantages and applications, the light-transmitting concrete has certain limitations. The major drawback of the light transmitting concrete is the cost, which is basically due to the cost of optical fiber and a special fabrication process. The manufacturing of LTC requires skilled labour and specialized moulds. The alignment of optical fibre and other transmitting materials is also a concern during the development of LTC. The incorporation of light-transmitting concrete has not significant increase in the strength compared to the other types of concrete and can be used as non-load-bearing structural components. The maintenance of LTC is an additional problem as the embedded fibre can attract dust or dirt, especially on the surface. A minimal proportion of light transmits due to the concrete's opacity and fiber density, constraining its efficacy for illumination. Optical fibers may deteriorate over time due to environmental conditions such as humidity or temperature changes, impacting long-term efficacy.

6. Future Scope

From the literature, it was found that most of the studies emphasized the mechanical strength and light-transmitting concrete under sunlight and artificial sources of lighting. The studies found that the placement of fibres and their fraction have an important role in the performance of transparent concrete. A very limited number of research studies have been conducted on the qualities of durability, as well as the impact of weathering action on the strength and light transmission of long-term construction materials, in addition to the microstructural characterisation. Additionally, the thermal characteristics are an essential component of the LTC that needs to be researched. There is a need for further investigation into the utilisation of resin as a light-transmitting concrete application. The life cycle analysis and life cycle cost analysis of the final product and its applications in the building received a negligible amount of attention and effort before its completion. The incorporation of various types of industrial by-products, such as fly ash, ground granulated blast furnace slag, silica fume, rice husk ash, and so on, was a gap in the light transmitting concrete that needed to be filled in order to research their performance under a variety of exposure situations. Studies can be conducted on the other materials that transmit light, as well as materials that have been researched less. Although the behaviour of light-transmitting concrete at elevated temperatures and the rate of heat transfer have not been explained, it is imperative that these aspects not be ignored. There is a direct relationship between the movement of heat and the cooling and air conditioning systems that are present in the area. As a result, reducing lighting costs while simultaneously increasing the temperature of the surrounding environment is not a feasible option.

7. Conclusions

In the present investigation, the performance of light-transmitting concrete was reviewed. This concrete was made up of a variety of translucent components, including plastic optical fibre, glass fibre, resin, glass waste, and others. Studies were conducted to investigate the characteristics of light-transmitting concrete, including its compressive strength, flexural strength, thermal conductivity, light transmittance, and energy savings, among other characteristics. The conclusions drawn from the various studies conducted on LTC are given below

- LTC has emerged as an innovative material combining aesthetic appeal with functional benefits, such as improved natural lighting and thermal insulation. It has promising applications in modern architecture, particularly in office buildings, galleries, and museums, where natural light integration and energy efficiency are desirable.
- The mechanical performance of LTC is influenced by several factors, including the volume fraction, diameter, and spacing of the optical fibres or other light-transmitting materials. Studies have shown that incorporating optical fibres into self-compacting concrete can enhance both compressive and flexural strengths.
- The maximum compressive strength was observed at 1.25% POF (plastic optical fibre) content. Higher optical fibre contents, such as 4% or 5%, and increased fibre diameters have also contributed to improved strength.
- Additionally, the use of supplementary cementitious materials like Ground Granulated Blast Furnace Slag (GGBS) and Fly Ash has resulted in compressive strengths up to 100 MPa and flexural strengths up to 17.5 MPa in transparent concrete.
- The incorporation of resin has also shown positive effects on strength and thermal insulation, up to an optimal proportion.
- However, certain limitations have been noted in the literature. The smooth surface and hydrophobic nature of optical fibres can hinder proper bonding with the concrete matrix, potentially reducing mechanical performance. Poor adhesion and increased porosity in some mixtures may contribute to reductions in compressive and flexural strengths.
- From an energy perspective, LTC can reduce lighting energy consumption by 32% to 46%, and panels embedded with 6% optical fibres have demonstrated up to 50% savings in lighting energy in office environments. These findings underline LTC's potential in sustainable design. Nonetheless, practical challenges remain, such as sensitivity to weather conditions and the accumulation of dust on the fibre surface, which may impact long-term performance.
- LTC is sufficient for office buildings, galleries, and museums, but more research is needed to consider different weather conditions and dust settling on the fibre surface.

Author Contributions

Conceptualization, K.S. and K.D.; methodology, K.S. and K.D.; validation, K.D.; resources, K.S.; data curation, K.S.; writing—original draft preparation, K.S.; writing—review and editing, K.D. and N.S.; supervision, K.D. and N.S.; project administration, K.D. and N.S. All authors have read and agreed to the published version of the manuscript.

Funding

This work received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Acknowledgments

The authors would like to express their sincere gratitude to Dr. Nitin Lamba, Assistant Professor, Noida International University, Noida, Uttar Pradesh, India, for their valuable support. Their insights and suggestions greatly enhanced the quality of this work. The authors thank the anonymous referee for their valuable suggestions.

Conflicts of Interest

The authors declare no conflict of interest.

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