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A Study on the Sustainable Solution for the Construction Industry: Mitigating Air, Water, Soil, and Noise Pollution through Pre-Engineered Structures

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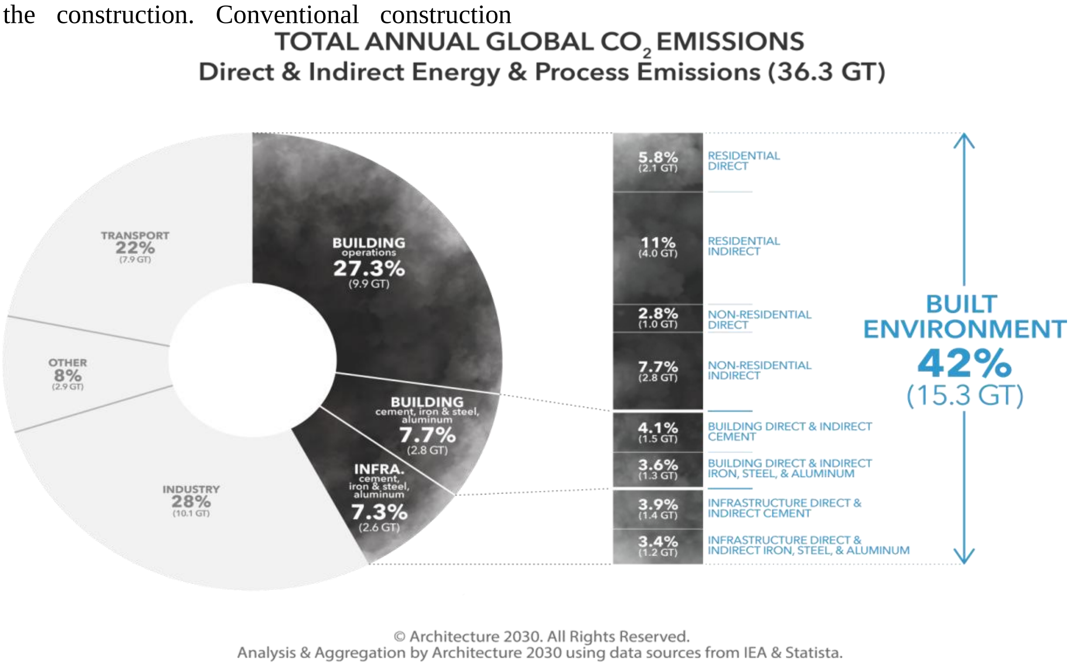
Abstract: ***Problem**: Construction Industry is proliferating significantly to accommodate the rising population in urban and rural areas globally, responsible for Environmental Pollution accounting for 27% of air pollution, 40% of water bodies' contamination along with Rapid Groundwater depletion and 50% of landfill waste also subsequently key issues includes Habitat loss, ecosystem disruption, waste generation and Noise pollution. Sustainable construction practices are essential to mitigate these impacts. We conducted this research to identify the sources and came up with a sustainable solution to protect natural resources and promote healthier environment for future generations. **Solution**: Pre-fabricated construction can mitigate environmental pollution in the construction industry by reducing carbon emissions, Controlling emissions of PM2.5 and PM10, minimizing water usage and wastage, minimizing waste generation and improving energy efficiency. Factories can manufacture components in controlled environments, leading to reduced energy usage and emissions compared to on-site construction. Pre-fabricated components can also be designed to optimize material use and incorporate recycled content, further minimizing the environmental impact. This research suggests that pre-casting\pre -fabrication can lead to a 10% carbon reduction for every cubic meter of concrete compared to traditional methods. Specific indicators are developed to evaluate projects' sustainability performance with various levels of prefabrication.*

Keywords: Environment pollution, water scarcity, pre-fabricated structures, sustainable construction, PM2.5 and PM10

1. Introduction

Construction Activities are majorly impacting the environment around us by reducing the quality of air through various kind of emissions discharged during the process of the construction. Conventional construction activities are consuming more water than the actual requirement, which is causing a major issue of water scarcity in the urban areas, degrading the water quality of the natural reservoirs and sources by accumulation of construction sediments and construction waste into the stream.



Due to prolonged use and wastage of groundwater in this construction sector it is found that the water table has drastically reduced to lower levels and it can deplete aquifers faster than they can be naturally replenished. In this research we have analysed various parameters which are influencing the environments on different levels. Uncontrolled construction activities are having serious consequences on the environment of the areas which are indulge in the major construction activities, in our research we found cities which are in Tier-1 and Tier-2 categories are severely affected with pollution caused by the construction industry. In a detailed study we have identified 6 major areas of impacts caused by the construction industry which are converting the green zones into smog covered built up areas.

Following are the various elements which are disrupted by conventional and uncontrolled construction practices which are dwelling in the industry-:

a) Air Pollution.
b) Water Scarcity and Water Pollution.
c) Habitat loss and Ecosystem Disruption.
d) Soil Degradation and Contamination.
e) Waste generation and Disposal Challenges.
f) Noise pollution.

These elements of earth which are responsible for making earth or surroundings suitable for living are polluted and disturbed by our own uncontrolled construction practices. In order to rectify these sustaining problems, we have created an approach towards the sustainable solution and found that by following this different approach towards construction method we can eliminate the degree of impact up to maximum, which can transform the construction industry in a positive way to resolve all of these impacting issues.

In an era where sustainability is paramount, industries across the board are seeking innovative solutions to reduce their environmental footprint. The construction sector, in particular, stands at a critical juncture where adopting eco-friendly practices are not just a choice but a necessity.

In our further research we will discuss this in details how we can reduce the environment pollution caused by the construction industry and save our Planet for the generations to come.

2. Literature Survey

In past researches there is always a concern about the pollution causing elements and it identifies them as vehicular emissions and greenhouse gasses released during production of materials. Various remedies and parameters are established to counter the effect of the air pollution but eventually it is not under control. Regarding construction activities no serious steps are taken into considerations to mitigate the environmental pollution caused by this dynamic industry. Similar to water pollution it identifies chemical spills and various factories with unregulated discharge in the water bodies. They were not able to establish co relation with this industry. In various studies it was found that construction activities produce carbon emissions and waste due to which there is certain accumulation in the pollution. But now this industry has gained heights in significant contribution in polluting the environment in multiple ways. Here in our research we have identified 6 different modules to study and rectify.

3. Problem Definition

In detailed review we found this a very serious issue and it is mandatory to bring sustainable solutions for this industry. Now we discuss in detail about all the above-mentioned issues.

3.1 Air Pollution

Environment has a major impact when its air quality is disturbed and it is one of the most important element of earth for sustaining the life on this planet. Bad air quality leads to bad human health and more prone to respiratory disorders especially in younger children and senior citizens. It also reduces the life expectancy of human beings. We would like to show how this C.I. (Construction Industry) referred as C.I. onwards, contributes in polluting the air:

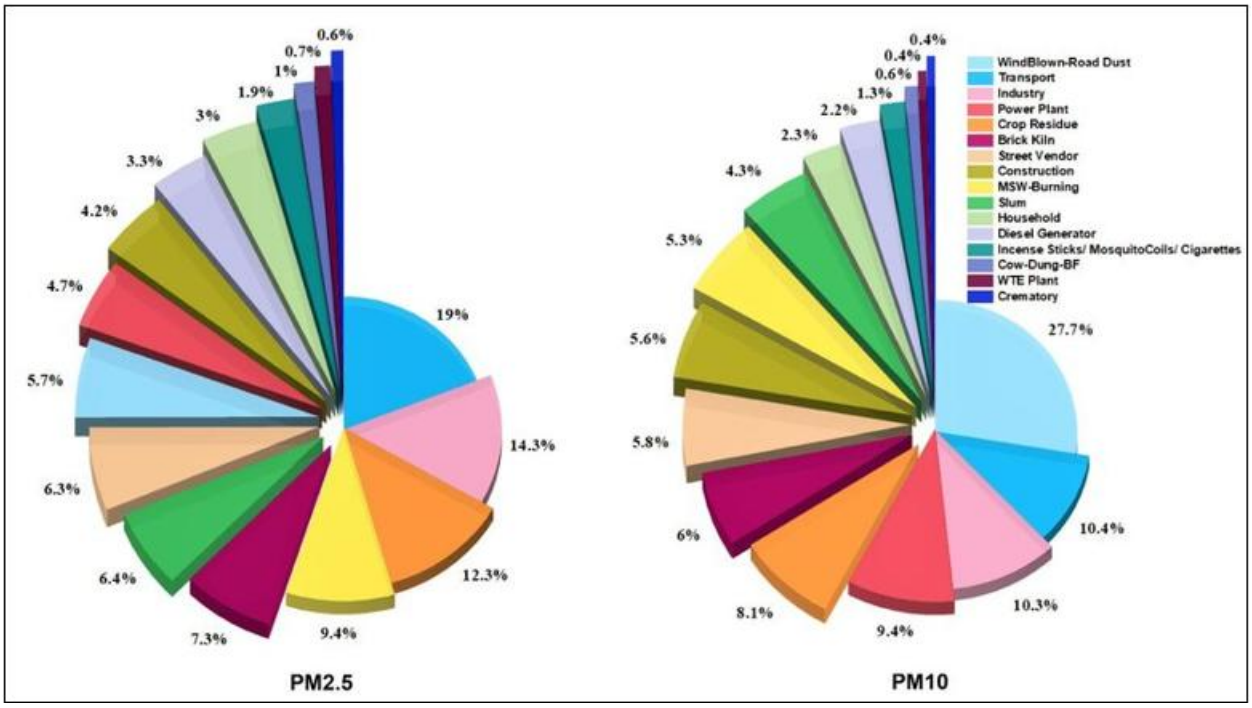
- Carbon emissions are generated by heavy construction equipment's and diesel operated machineries during the process of construction start to end.
- Huge amount of dust and carbon emission is generated due to movement of large fleet of raw material carrying vehicles into urban area and construction sites.
- PM2.5, PM10 and Dust Particles are released into air during unloading of raw materials at site and feeding into the RMC plants. This dust and particulate matter is carried away into surroundings by flowing winds at distant levels.
- The main sources of air pollution from construction project processes were demolition works, quarry sites, machinery/equipment, and on-road traffic carrying soil and loose construction materials.
- Construction sites are responsible for generating a high concentration of pollutants in surrounding air. Emission level can be different depending on the materials used for the construction.
- During strong winds construction materials (Fine sand, Stone Dust, Cement, Gypsum, Marble dust) loosely stored in open situations are tend to carried away by the wind creating accumulation of particulate matters and toxicity in the air.
- Concrete dust released by building demolition and natural disasters can be a major source of dangerous air pollution. The presence of some substances in concrete, including useful and unwanted additives, can cause health concerns due to toxicity and (usually naturally occurring) radioactivity.

Problems due to these emissions are:

- Increasing air pollution emissions, leading to challenges for the site workers and residents dwelling around the construction site.
- This study established that the most predominant air pollutant of concern released during construction project activities is particulate matter. Other air pollutants, such as carbon monoxide and oxides of nitrogen, were also identified which are main cause of respiratory disorders and serious respiratory issues if exposed for longer durations.

3.2 Water Scarcity and Water Pollution.

Another major impact assessment is done with water, which is used during the construction process and also which is polluted during the construction activities. Construction activity uses water to a significant extent for many operations, materials, and on-site activities, and the availability of potable water for building construction is a matter of concern. Consumption of water in building construction is expected to increase across the globe, particularly in developing countries like India, because of the demand for urban development and housing for all. Hence, water efficiency in building construction is a matter of concern when it is used poorly and inefficiently.



Construction activities can have long-lasting impacts on receiving water bodies, especially when they receive polluted urban run-off**.** This suggests that the consequences of construction-related pollution can have long-lasting effects on water quality and may require on-going efforts to mitigate and manage the impacts.

3.2.1 We would like to show how this C.I. contributes in consuming the water extensively with no control over the wastage :-

- Public buildings have larger footprints than residential buildings because of their intensive consumption of steel and cement and larger covered area which requires more consumption of water.
- Compared to rural residential buildings, the footprints of the urban residential buildings are 55–130% higher. Hence resulting in continuous depletion in water table in urban areas.
- Due to extensive involvement of residing manpower in urban construction projects , per capita demand of water is rises in tremendous amount which can multiply the usage of water up to 130% of total water requirements of construction activities.
- Continuous extraction and poor distribution system of groundwater through bore holes at construction sites to fulfil the demand of residing manpower is the main reason for the wastage and excess extraction of groundwater. This will significantly depletes the aquifers and it will be a troubling situation for the urban areas. **(Similar example was came in light in Bangalore, India, when there was crisis for the water. As there was no availability of water for washing, drinking and even there was no availability for bathing.**
- The National Remote Sensing Centre and 2019 study estimated that India's average annual water resource availability was 1,999.20 billion cubic meters (BCM). The country's usable water is thought to be 1,126 BCM in 2023 due to geographical, hydrological, and other limitations.
- In a detailed analysed model of multi-story residential apartment structure it was determined that the inherent and induced water levels were 25.6040 kl/sqm and 2.0kl/sqm, respectively, of floor area. As a result, the construction water footprint came to 27.6040 kl/sqm. But the actual requirement of the water for only civil construction related activities was 0.6 kl/sqm. Excess consumption was 27.0 kl/sqm .
- In different research it comes as a result that a conventional building construction in Jammu uses 43.7 kl/sqm of embedded water per square meter. 40.3% of the total embodied water in buildings comes through indirect water consumption.
- Water required for curing of materials like brickwork in cement mortar, cement plaster, and concrete is considered as 10% (by volume) by bricks and cement mortar and 5% (by volume) by cement and concrete for 7 to 14 days on a daily basis.

3.2.2. We would like to show how this C.I. contributes in Water pollution:

- Accumulation of the particulate matters and insoluble particles such as cement, dust and gypsum particles in the water bodies resulting in the reduction in the percolation of water in the ground which hampers the recharge of aquifers.
- During construction works, which are typical human activities during urban development, it is likely that the levels of dissolved solids or salinity in water will be elevated above natural levels. Regarding suspended solids, previous studies have shown that construction works lead to relatively high levels of suspended solids

in streams because of the wash off of construction sites that release into runoff.
- Runoff from construction sites containing sediment, chemicals, and debris can contaminate water bodies, impacting aquatic life and potentially human health.
- Improper waste disposal and spills of hazardous materials can also lead to water pollution.

3.3 Habitat Loss and Ecosystem Disruption.

Another impact on the environment is caused by the C.I. is the permanent loss of habitat of animals which leads to migration or extinction of several species of animals and birds in the construction zones and surroundings. It is also found during the research that there is a significant amount of depletion in green zones and vegetation in the areas of running projects and surroundings.

3.3.1. We would like to show how this C.I. contributes in Habitat loss and Ecosystem disruption:
- Construction activities often involve clearing land for development, leading to habitat loss and fragmentation, disrupting ecosystems and biodiversity.
- Construction projects generally acquire vast area rather that built up area to accommodate the machineries, plants, temporary accommodation settlements for workers and raw materials, which causes a great loss of habitat and loss to vegetation (due to removal of greenery and plants), soil degradation and pollution in the water bodies.
- A construction project often begins by tearing down existing structures or clearing away inconvenient habitat, which can disrupt or harm wildlife.
- The noise and light from on-going construction can disrupt species' feeding or breeding behaviours, (mostly for birds) and the disruption of the land can divide large habitats into smaller ones, impacting species that rely on spacious habitat. An active construction site can also attract wildlife to an unsafe area.
- Noise and other disturbances from construction can disrupt wildlife behaviour, including feeding, breeding, and migration.
- Traffic, construction vehicles, unwanted human presence and other factors associated with construction can increase wildlife mortality.
- Construction can disrupt soil and vegetation, leading to increased erosion and sedimentation, which can damage aquatic habitats and impact water quality. Sedimentation of toxic particles over the large area of land results in toxicity of soil and depletion in vegetation growth.
- Changes in water levels, extinction and pollution of water body areas and vegetation cover in the conservation area all directly affect the availability of water bird habitats, which can affect water bird diversity.

It may not seem surprising, but development significantly impacts natural ecosystems. Habitat loss manifests itself in various ways, and an area does not have to be entirely destroyed to experience long-term consequences. Companies should apply wildlife-friendly measures when starting a new construction project, such as identifying vulnerable species, essential habitats, and the impact on migrating birds. While we generally consider land animals the most vulnerable to habitat loss, the built environment affects aquatic and bird species equally.

3.4 Soil Degradation and Contamination.

Soil Contamination is also a resultant of this construction industry. Continuous degradation of soil and contamination is prominently arising due to certain factors:
- Improper handling of raw materials laying at construction sites.
- Spreading and disposal of debris with dust and particulate matter in the open which is carried by strong winds in significant time.
- Sedimentation of cement particles, gypsum, silica, stone dust over the ground causing toxicity in soil resulting in soil degradation.
- Mixing of soil with leftover raw materials over a period of time due to improper material management and poor construction practices promotes the contamination of soil by losing its adhesive strength and fertility.

3.5 Waste generation and Disposal Challenges.

Waste generation and disposal is one of another major environment related issue which is a by-product of the construction industry. Construction projects generate large volume of garbage and debris which is generally the demolition waste. A study found that in India building and demolition operations generated 765 tons of debris due to demolition of old structures which are demolished to expand and renovate.

3.5.1 It is becoming more challenging due to certain factors:-
- Construction industry generates large amount of loose garbage like packaging of polymers and other cardboard which end up in landfills or incinerators, which emit smoke and huge carbon emissions on burning into the atmosphere. Both ways of disposal have negative impact on the environment.
- Contraction trash is one of the top contributors to industrial waste. Demolition project contribute to nearly 90% of that amount meaning most of the demolished material is never re used.
- Loose and improper collection management of waste in construction sites results in littering of waste resulting the waste end up in river bodies causing degradation of water and aquatic life.
- Landfills are the major disposal sites for debris and other structural components including concrete and broken bricks which hamper the process of decomposition of waste.
- Due to heavy weight of debris and demolition waste sometimes it is not disposed in landfills but it is disposed near the construction sites into the soil to reduce the disposal cost.

3.6 Noise Pollution.

Construction has a negative impact on the environment because of noise pollution. There's no way around it: construction equipment is noisy, and these noises may wreak havoc on the surrounding environment, particularly in a residential area. The various types of machinery used in excavation, demolition, construction, and landscaping contribute to noise pollution. Noise can cross the threshold limits during the peak working hours. Adverse effects on the environment are:

- Due to heavy machinery involvement noise levels can be very high during daytime and even at night for the night shifts.
- Prolonged exposure to these noise levels individual can face mood swings and behavioural changes and permanent hearing loss.
- Due to continuous noise during day and night certain species of the birds and animals tend to migrate and it causes habitat loss and disturbance in migration patterns.
- Due to noise levels there is always a risk of accidents at construction sites due to negligence of warning sounds.
- Elderly people and patients find it very disturbing in sleeping and relaxing resulting in stress and anxiety.

4. Rectification Methods / Approach

After evaluation of all the problems caused by construction industry it becomes challenging to mitigate all of these problems in the industry. In this research we have calculated the merits of certain construction methodology over the conventional methods of constructions after that we found that there are implications showing positive signals which enhance the environmental conditions.

We find the solution in the form of Pre-fabricated modular technology (PMT). In this tech various components of structures generally of residential projects which are more prominent in the urban areas, are calculated, designed and fabricated in a pre-planned and sustainable factory under controlled conditions in which it kept in mind to mitigate all the above mentioned problem which are affecting the environmental conditions.

Conventional cast in-situ, precast and prefabricated construction are construction methodologies with increasing construction modularity. Construction methodologies and modularity, in turn, are determinant of sustainability on site. This paper analyses 5 construction projects in **Rail Coach Factory, Rae Bareli, U.P., India**. Spanning a substantial period of 10 years for a systematic comparison on their construction methodology and sustainability performance. Specific indicators are developed to evaluate projects sustainability performance with various levels of prefabrication.

Environmental sustainability indices capture the carbon emissions and waste generation of projects. Social sustainability indices represent the human resource usage and overall accident rate of projects. Economic sustainability indices denote the project cost and time used for completion.

Finally, a composite sustainability index is compiled. The study finds significant positive correlations between the percentage of prefabrication applied onsite and the sustainability attributes. Detailed project analysis further suggests that the highest sustainability performance was found in projects that adopted Pre-Fabricated Modular Technology (PMT) as the primary construction methodology.

Use of **Ultra-High-Performance Concrete (UHPC)** is a revolutionary material that has been gaining popularity in the field . UHPC is a type of concrete that is known for its exceptional strength, durability, and versatility. It is made with a precise combination of ne sands, cement, silica fume, bars, and super plasticizers, resulting in a material that is far superior to traditional concrete in terms of performance and durability. One of the key characteristics of UHPC is its incredibly high compressive strength, which can exceed 20,000 psi. This strength allows for the creation of slender and innovative architectural designs that were previously not possible with traditional concrete. UHPC also has a very low permeability, making it highly resistant to corrosion and environmental degradation. This durability ensures that structures built with UHPC will have a longer lifespan and require less maintenance over time.

Another benefit of using UHPC in construction process is its rapid setting and high early strength development. This allows for faster construction times and reduced labour costs, as structures can be erected more quickly and efficiently than with traditional concrete. Additionally, the high early strength of UHPC means that structures can be put into service sooner, reducing downtime and increasing productivity on construction sites.

Structural design principles for precast concrete elements are crucial in ensuring the safety and durability of precast concrete construction projects. As civil engineers, it is essential to understand these principles to effectively design and build precast concrete structures. By following best practices in structural design, you can optimize the performance and efficiency of precast concrete elements.

4.1 Social sustainability

In relation to social sustainability in construction, the safety and working environment of construction workers are key considerations. Firstly, safety is considered as one of the many methods in improving sustainability. As accident rate was kept based on the entire project lifecycle, further attributing the associated injuries or fatalities to specific operations of different construction methods is difficult. Overall it shows that precast and prefabricated construction could provide a safer working environment for workers and therefore reduce the accident rate. Jaillon and Poon (2008) have mentioned that the use of prefabrication would allow a better and safer working environment for construction workers. A report by the Construction Industry Review Committee (Construction Industry Review Committee and Tang, 2001) also recommends prefabrication methods as feasible ways to reduce accidents associated with the cast in-situ construction method. Other benefits of prefabricated construction towards workers health include a reduction of noise and dust onsite, which, in turn, can reduce the degradation on occupational health of workers. Apart from improved occupational health and safety of workers, the study demonstrates that productivity, site management and quality of works have increased when adopting prefabricated construction

Academic research and world organisations have also included a reduction of resource consumption as one of the seven indicators of sustainable construction (Zhong and Wu, 2015). Considering the reducing labour resources in Tier 1 and Tier 2 cities, prefabricated construction enables a reduction in required human resources onsite, as most construction materials are built offsite and only required installation onsite. Labour shortage in the construction industry is severe among many big cities. This study also suggests that prefabricated construction allows for a better supervision of labour when compared to the conventional cast in-situ method.

4.2 Economic sustainability

During the research many evidences indicate that higher levels of construction modularity can effectively reduce the materials required for construction projects. With better quality provided by offsite construction, reworks onsite and material wastage are minimized. Therefore, the economic liability for materials can also be reduced. A study focusing on the performance of prefabricated construction has shown that it can significantly reduce material cost by 56% when compared to the cast in-situ method (Jaillon and Poon, 2014). As prefabrication allows quality control over production, the cost for material deliveries, storage or reworks is also less of a concern. It provides a chance to closely monitor the production in controlled facility.

5. Results / Discussion

Pre-Fabricated Modular Technology (PMT) as a Solution.

Pre-Fabricated Modular Technology (PMT) can mitigate environmental pollution in the construction industry by reducing carbon emissions and a significant reduction in PM2.5 and PM 10 emissions, minimizing waste, and improving energy efficiency. Factories can manufacture components in controlled environments, leading to reduced energy usage and emissions compared to on-site construction. Precast concrete can also be designed to optimize material use and incorporate recycled content, further minimizing the environmental impact.

During this detailed research we found that PMT technology can contribute to the environment and change the scenario of the construction industry in a very positive way. It helps in replenishing the environmental pollution to a greater extent. We found certain results during the study:

5.1 Reduced Carbon Footprint and reduced PM2.5 and PM10 emissions.

Reduction in carbon emissions and PM2.5 and PM 10 with overall reduction in carbon footprint of construction projects due to minimal use of vehicles except transport vehicles which are used to transport the fabricated components to site. **Over all complete reduction in air pollution**.

- **Factory Production:** Manufacturing pre-fabricated concrete components in controlled factory settings allows for optimized energy usage and reduced greenhouse gas emissions compared to on-site construction.
- **Efficient Material Use:** Precast design can optimize material use, potentially reducing the amount of concrete required and the associated carbon emissions from cement production. Also regulates the optimum use of raw materials conserving the limited resources.
- **Carbon Reduction:** Studies suggest that pre casting or pre fabricating can lead to a 10% carbon reduction for every cubic meter of concrete compared to traditional methods and reduce energy consumption in the process of casting.
- **Low-Carbon Cement:** The precast industry actively seeks to reduce cement usage and replace it with alternatives like fly ash, slag cement, and silica fume, which further reduces carbon emissions.

5.2 Reduced waste generation.

- **Minimizing Waste:** Precast construction generates less waste due to its controlled manufacturing process and the use of reusable formwork. It also control the waste related to packaging materials and store them in controlled conditions. Zero waste policy is maintained in the pre cast facility.
- **Waste Recycling:** Waste concrete from precast plants can be recycled for use in other construction projects or as fill materials. Water used for curing of casted elements is also recycled and used in further curing process. It minimise the use of water in the construction process.
- **Reusable Formwork:** Formwork and finishing materials can be reused multiple times, reducing the need for new materials and associated waste.

5.3 Improved Energy Efficiency:

- **Optimised Design:** Precast components can be designed to improve building performance, such as thermal insulation and energy efficiency, leading to reduced energy consumption .
- **Reduced Energy Use:** By manufacturing components in a factory setting, energy consumption is optimized and emissions are reduced compared to on-site construction. Components are customised to consume least power consumption during installations and errection.

5.4 Other Benefits:

- **Reduced Noise and Dust:** Precast construction reduces noise and dust pollution on site compared to traditional construction methods. Use of lesser mechanical means at site.
- **Faster Construction:** Precast construction can accelerate the construction process, reducing the time spent on site and minimizing the environmental impact of long-term construction activities reducing the construction cost and minimizing the engagement of manpower and machineries.
- **Improved Safety:** Precast plants can offer a safer working environment compared to traditional construction sites, reducing risks associated with manual labour and machinery. Due to easy installation process skilled manpower can assemble it with least risk of accidents.

Precast concrete contributes to sustainable practices by incorporating integrated design, using materials efficiently, and reducing construction waste, site disturbance, and noise. The concept of sustainability, however, balances sustainable design with cost-effectiveness Precast concrete panels can be reused when buildings are expanded.

5.5 Durability

A key factor in building reuse is the durability of the original structure. Precast concrete panels provide a long service life due to their durable and low-maintenance concrete surfaces. A precast concrete shell can be left in place when the building interior is renovated. Annual maintenance should include inspection and, if necessary, repair of joint material. Modular and sandwich panel construction with concrete exterior and interior walls provides long-term durability, inside and out. Precast concrete construction provides the opportunity to refurbish the building if the building use or function changes, rather than tearing it down and starting anew. These characteristics of precast concrete make it sustainable in two ways:

It avoids contributing solid waste to landfills and it reduces the depletion of natural resources and production of air and water pollution caused by new construction.

6. Conclusion

We would like to conclude that for the preservation of our eco system it is mandatory to safeguard the parameters of environment. It is the need of hour to control the deteriorating situation of environment by adapting the pre-fabricated technology (PMT) in the construction industry especially in the urban areas where the density of the population is very dense. This technology not only reduces the pollution but also conserve the most precious element that is WATER.

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