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Adaptive and Sustainable Design for Building Construction Considering Climate Change

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ABSTRACT

The two most crucial factors that are constantly taken into account while developing or building any new infrastructure in this day and age are sustainability and resilience. In a similar manner, this project centers on the same idea of sustainability and resiliency in order to construct a 10-story structure that served the function of a multipurpose community center equipped with cutting edge technology and carefully selected construction materials in order to lessen the number of harmful emissions and to keep a balance in both the structural strength and the environment. The design process has involved choosing the primary building material, the type of construction used, the building plans, and the carbon footprints the selected building materials are generated. The building's planned design also assessed for structural soundness, environmental sustainability, and resilience. The outcomes are compared to an existing structure in the same domain for the critical evaluation and effective decision-making. As a result, this compilation also includes a complete and in-depth analysis of how the suggested construction is more robust and sustainable. The preface also includes information on the building parts, such as the materials used to contrive the structural as well as the non-structural members. In the end, the suggested design is monitored based on its structural qualities to ensure its stability and resilience. In order to successfully propose a sustainable and resilient design for the building of a multipurpose 10-story community center, a comprehensive and optimal set of recommendations is provided.

Keywords: Sustainability, Resiliency, Construction, Climate Change

INTRODUCTION

An adaptive and sustainable design plays a vital role in the prevention of buildings from climate changes observed in the dynamic world. The concept of sustainable and resilient design is explored in multi-directions, including the social, economic, health, building performance and other environmental factors as well. Sustainable principles daunt the practice of non-renewable natural resources, which are helpful in enhancing resource conservation. The multi-structured building considered for climate change, including structural and non-structural members, need in-depth assessment for material, strength, harmful emissions, environmental sustainability, and resilience.

In sustainable and resilient building design, the role of climate change is vital, which includes several seasonal and non-seasonal natural phenomena like humidity, wind, rain and other temperature changes. Based on record, the expected increase in temperature falls between 1.8°C to 4.0°C at the end of 2tst century (Long, 2021).

Climate change increases global warming and affects building performance which has become a constant pressure in the construction industry. Developed countries have proper building policies and standards which help in reducing carbon footprints and temperature to have control over diseases. Selection of building material according to revised building codes is important and regular maintenance also increase the resilience of the building. Passive building designs also help to deal with difficult situations (UNEP Sustainable Buildings & Climate Initiative, 2009).

Carbon footprints need to be controlled during the construction phase by having an appropriate timeframe and good consumption of material to decrease operational energy. The study has shown an increase of 5 million tons of carbon footprints from 2005 to 2009 (Sizirici B, 2021). Carbon footprint control techniques like recycling products and materials have worked well. Also, sustainable and resilient buildings are one of the best options to get over ecology stress.

RESEARCH METHODOLOGY

DATA COLLECTION

The data presented in this paper was gathered through the consideration of various research approaches specifically linked with the design of buildings with 10 stories and calculations of carbon emissions. After it has been designed, the building with ten stories judged against another structure of a comparable size in order to determine how well it performs in terms of its resilience and sustainability.

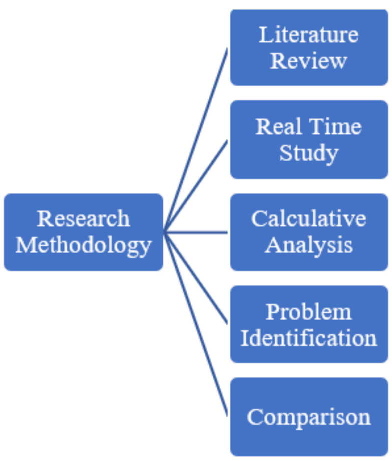
DESIGN APPROACH

The community centre that housed in the designed ten-story structure state-of-the-art and feature separate areas for administrative tasks, social and public gatherings, cafes, recreational activities (games, rides, etc.), and also included a swimming pool. The structure was designed in accordance with all applicable building codes as well as the general requirements outlined in design standards. All of the structural elements are designed using appropriate calculations that take into account combinations of dead load and live load, in addition to other requirements.

CALCULATIONS OF MULTIPLE ASPECTS

The following is a list of the computations that are going to be included in this research paper:

• The total volume of concrete that was used in the construction of each floor's structural members.
• The total amount of wood that was used in all the structural members, floor by floor.
• Calculating the associated levels of carbon emissions (based on construction materials).



RESULTS AND DISCUSSION

SELECTION OF MATERIAL

For the building's construction, the following two concrete proportions are selected:

M15 (1:2:4) CONCRETE MIX

In the M15 concrete mix, 15 MPa(N/mm2) is the compressive strength of the cement which is 2175 in psi. Compression strength defines the ability of a material to resist after the application of compressive force. The proportion of 1:2:4 represents cement, sand and aggregate, respectively. In terms of percentage, it becomes 14.28%, 28.57% and 57.14%, respectively. Furthermore, the quantity of steel is considered for building construction, which cannot be finalized based on concrete grade, but the type and dimension of structural members, including the total area of a 10-story building and the concrete amount for holding reinforcement, is supposed to be determined. The water-to-cement ratio for M15 ranges between 0.4-0.6, while steel% for slab, beam, column and foundation are 0.7-1, 1-2, 0.8-6 and 0.8, respectively, for a 1-meter cube of concrete.

M20 (1:1.5:3) CONCRETE MIX

In M20 concrete mix, 20 MPa(N/mm2) is the compressive strength of concrete which is 2900 psi, and the proportion of 1:1.5:3 represents cement, sand and aggregate, respectively, which makes 18.18%, 27.27% and 54.54% in the same order. The water-to-cement ratio is 0.42, and the %steel for structural members like slab, beam, column, and foundation have ranges 0.5-1.5, 1-1.5, 2-3 and 2-5, respectively (Civil Sir, 2018).

While making a comparison between M15 and M20, it is finalized that M20 is better in terms of compressive strength, stability under tension with a 13.33 modular ratio (modulus of elasticity of steel/modulus of elasticity of concrete) and strong binding, but the main problem is with the environment. M20 produce CO_2 and increases global warming, which is not suitable for climate change. While M15 has 15 compressive strength, 18.86 modulus ratio and 14.28% less cement content as compared to M20, causing fewer oxides of cement, it is eco-friendly, which produces less air pollution and is considered best for climate changes and is budget-friendly too.

CONCRETE CONSTRUCTION TECHNIQUES

PRECAST CONCRETE

Precast concrete is one of the types of concrete which is prepared in a rebar framework away from the original site, but the conditions remain the same. After the curing and hardening, it is transported and assembled into the structure under construction. The precast concrete method is suitable for a multistory building having prefabricated structural members as per standards. It can be a Large Panel system (Multistory buildings) and a Frame System (Beam-columns assembly for multistory buildings).

THE SUSTAINABILITY OF PRECAST CONCRETE

Precast concrete can work on all structural members of the building, but it makes relatively heavier members. It offers good elasticity and quality with more durability of members. The use of material makes it cost-effective and eco-friendly, with no on-site construction. On the other hand, it subsidizes chamber formation of structural elements (columns and beams). Also, it is costly in terms of member transportation, including the connections and joints (ResearchGate, 2016).

CAST-IN CONCRETE

The preparation of framework, curing, hardening and filling of concrete is ensured on-site for cast-in concrete. It is suitable for load-bearing walls and foundations made by a certain grade and by taking the shell out or by filling the driven metallic shell, which is cured till the desirable durability and compressive strength are obtained. Also, the vibrator is used to make concrete consistent in the framework along with reinforcement.

THE SUSTAINABILITY OF CAST-IN CONCRETE

Cast-in concrete offers a variety of shapes, sizes, surfaces and textures, along with easy connections for a 10-story building. At the same time, the heavy machinery, more labor and time-consuming fabrication of reinforced framework are tricky to handle. Furthermore, consistent and standardized quality is challenging to retain. While making a comparison between precast concrete and cast-in concrete, precast concrete is recommended based on the consistency and homogenous quality of the structural members of a multi-story building. Also, the carbon footprints are reduced by eradicating harmful pollutant yield at the time of concrete production. The overall procedure results in the maintenance and sustainability of the environment while constructing a multi-story building. Precast concrete is friendly in terms of eco, economics, material quality and resilience. The optimal curing, labor efficiency, short-time hardening and resistance against climate change make precast concrete sustainable and a good option to consider for the construction of a 10-story building.

CALCULATIVE ANALYSIS

VOLUME & STEEL WEIGHT CALCULATIONS

TABLE 1. Column Calculations

Column calculations	Column Height (m)	Column Size (m)	No of Columns	Volume of 1 Column (m^3)	Volume of concrete in 25 Columns (m^3)
(One Floor)	3.850	0.750 x 0.750	25	0.750 x 0.750 x 3.850 = 2.16	2.16 x 25 = 54

TABLE 2. Slab Calculations

Slab calculations	Slab Thickness (m)	Slab Size (m)	Concrete Volume in Slab (m^3)
(One Floor)	0.150	33 x 33	33 x 33 x 0.150 = 163.35

TABLE 3. Beam (One Floor) Calculations

Beam (One Floor)	Length (m)	Width (m)	Depth (m)	No of Beams (m)	Volume of Concrete in 1 Beam (m^3)	Volume of Concrete in 20 Beams (m^3)
Beam Type -01	7.125	0.750	0.450	20	7.125 x 0.750 x 0.450 = 2.4	= 2.4 x 20 = 48
Beam Type -02	7.50	0.750	0.450	20	= 7.50 x 0.750 x 0.450 = 2.5	= 2.5 x 20 = 50

TABLE 4. Total Concrete Volume

	1 Floor (cum)	10 Floor
Total Concrete Volume (cum)	Column + Slab + Beam-01 + Beam-02 = 54 + 163.5 + 48 + 50 = 315.35	Column + Slab + Beam-01 + Beam-02 = 315.35 x 10 = 3153.5 cum = 80 x 3153.5 = 252,280 kg = 252.28 tons

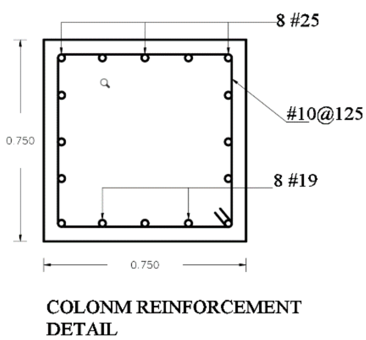


FIGURE 1. Column Design Details

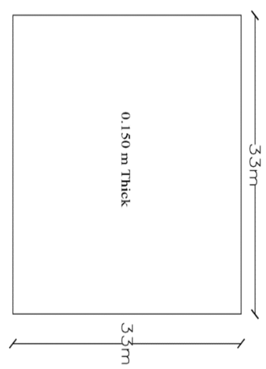


FIGURE 2. Slab Design Details

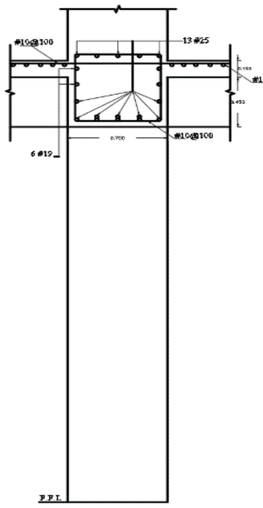


FIGURE 3. Beam Design Details

TABLE 5. Carbon Emission from Concrete

Carbon Emission Calculation from concrete of Designed Building	Total Volume of Concrete (cum)	20MPa Concrete (per cum) emits CO_2 (kg)	Total Emissions
Carbon Emissions from Concrete for All Floors	3153.5	328	= 328 x 3153.5 = 1034348 kg CO_2 emissions

TABLE 6. Carbon Emission from Steel

Carbon Emission Calculation from steel of Designed Building	Steel bar emits CO_2 (kg)	Total Emissions
Carbon Emissions from Steel (Columns + Slabs + Beams) For All Floors	2.1	= 2.1 x 252,280 = 529788 kg CO_2 emissions

TABLE 7. Carbon Emission from Glulam Floors

Carbon Emission from Treet Building	4 floors Volume	1 m3 Glulam	CO_2 emission	Volume Concrete Slab (5)	Concrete Slab Emissions
Glulam Floors	550 m^3	1718 kg CO_2 e	= 550 x 1718 = 944900 kg	1250 m^3	= 5 x 1250 x 328 =2050000 kg CO_2 e

TABLE 8. Carbon Emission from Remaining 10 Floors

Carbon Emission from Treet Building	CLT Volume for 1 Floor	CLT Volume for Floors	1 m^3 CLT emits CO_2	CLT CO_2 emissions
Remaining 10 Floors	385 m^3	=10 =385 m3 x 10 =3850 m^3	645 kg	=3850 x 645 =2483250 kg

TABLE 9. Proposed 10 Story Building and Treet Building

Proposed 10 Story Building	Treet Building
Total CO_2 emission for the concrete = 1034348 kg CO_2 e	Total CO_2 emission for glulam = 944900 kg CO_2 e
Total CO_2 emission for the steel = 529788 kg CO_2 e	Total CO_2 emission for Concrete Slab = 2050000 kg CO_2 e Total CO_2 emission for CLT =2483250 kg CO_2 e
Total CO_2 emission = 1564136 kg CO_2 e	Total CO_2 emission = 5478150 kg CO_2 e

DISCUSSION BASED ON RESULTS

It has been determined through these calculations and the results obtained that the Treet building emits a greater amount of carbon than the designed building. In comparison to the Treet building's use of Cross laminated timber and glulam as its primary building materials, the proposed design for the fifteen-story building, which uses reinforced cement concrete as its primary building material, is the more environmentally friendly option (GIATEC, 2020).

EVALUATION OF THE DESIGN'S LONG-TERM SUSTAINABILITY AND RESISTANCE TO FAILURE

The standard building has a heat recovery installed ventilation system, district heating system, timber as primary and concrete as secondary material. In contrast, a 10-story designed building has a heat recovery proposed ventilation system, heat exchanger system, and concrete as primary and timber as a secondary building material. There are three stages of construction for a typical high-rise (levels 1–5, 6–10, and 11–15), while a custom-designed structure has only two (levels 1–5, and 6–10) (DataStreet, n.d.). Comparatively, the designed building has sliding windows with triple glazed low emissivity glass, load bearing framework in only the seventh floor, a single hinged swinging door made from oak wood with stainless steel frame, and concrete slab on the seventh level, while the standard building has windows with low emissivity glass with an aluminum frame, load bearing framework at every fourth floor, wooden doors, and concrete slab on the ground, fifth, tenth, thirteenth, and fourteenth floors. Standard buildings in this area of Hordaland, Norway (which has a coastline) have an underground parking system and several refreshment points, but the designed building has ground parking on all four sides and features a swimming pool, fitness center, and restraint on its roof. The total construction area is 7140 square meters. For long-term viability and defence against severe weather, there is metal cladding at the left, right and back sides to protect concrete from extreme weather conditions and steel plates with dowels as joints. In comparison, designed multi-story building have metallic cladding on the 10th level because of concrete as a primary material in construction, including anchor bolts to join columns, beams and slabs; steel plates and dowels are used to make timber connections (Slideshare a scribd company , 2015). The required graphical representations are as follows:

FIGURE 4. Treet Building (Research, 2022)

FIGURE 5. Front Elevation of Designed Building

FIGURE 6. Proposed Ground Floor Plan

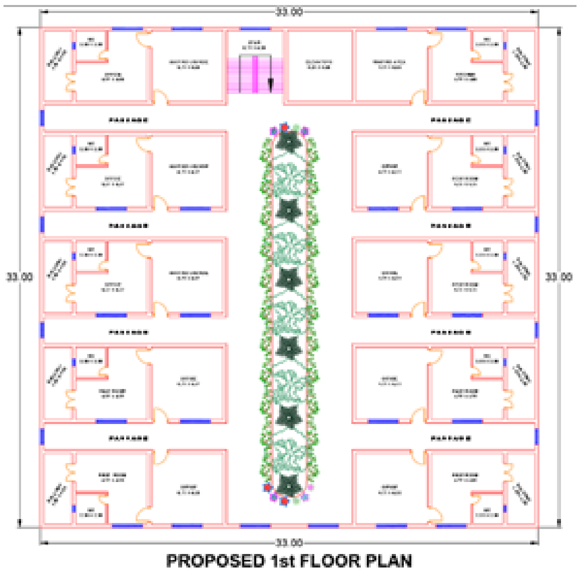


FIGURE 7. Proposed 1st Floor Plan

FIGURE 8. PROPOSED 2ND FLOOR PLAN

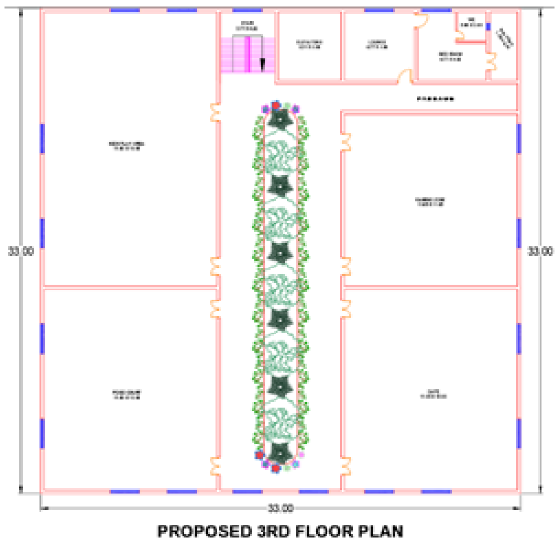


FIGURE 9. Proposed 3rd Floor Plan

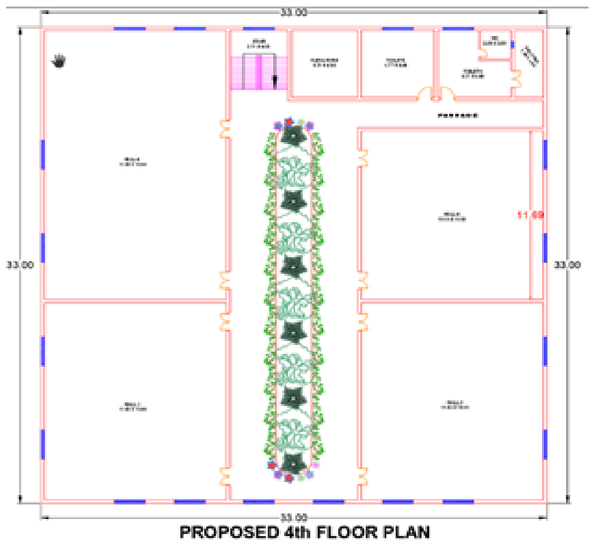


FIGURE 10. Proposed 4th Floor Plan

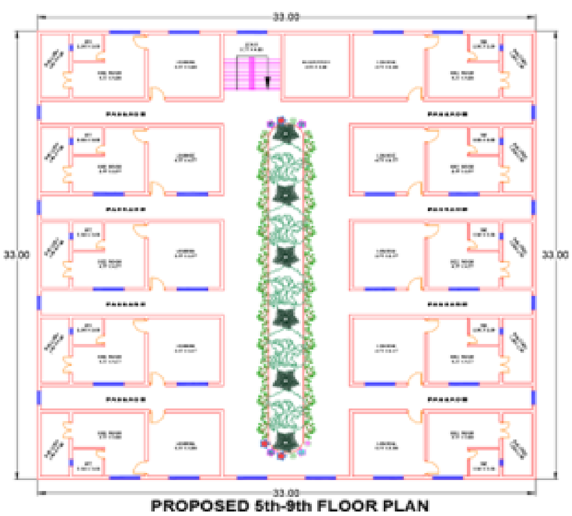


FIGURE 11. Proposed 5th-9th Floor Plan

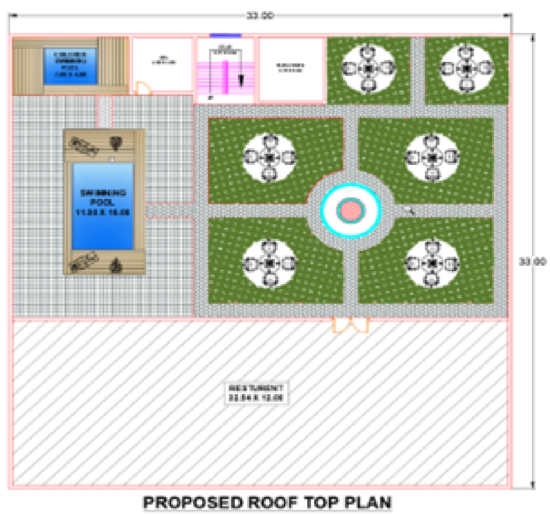


FIGURE 12. Proposed Roof Top Plan

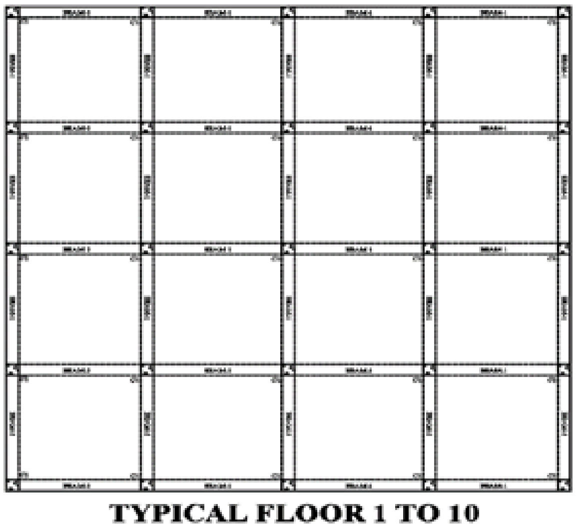


FIGURE 13. Typical Structural Plan 1 to 10

CONCLUSION

This research was to put forward the study of sustainability and resilience of 10-story building design as per the standard criteria. Sustainability is associated with environment-friendly structures emitting less carbon emission footprints, and resiliency is the tendency of a building to sustain against disaster with redundancy and robustness. Sustainability is achieved through advanced techniques to undertake CO2 emissions from materials, while resiliency is obtained by making the right selection of material type, reviewing soil characteristics, and studying reinforcement.

The design procedure includes analysis of topography and construction area, which leads towards the drafting of floor plans with necessary components and elevations were made. After that, M20 grade concrete with S-355 grade steel is selected as the primary construction material for structural members (column, beam, slab etc.), while timber is a secondary material for building elements (doors, windows and frames). Furthermore, aluminum and stainless steel for framing, low emissivity glass with triple glazing for windows, hybrid ventilation system, heat exchange system, condenser boiler, glazing and insulation are ensured to reduce the CO2 emission (Difference Between.net, 2022). Apart from that, a well-thought-out analysis was made to select techniques of concrete construction (M20, M15, precast concrete, cast-in-place concrete) with a type of foundation. The calculation for volume and quantity of concrete is also made. Lastly, the comparison of designed 10-story building is made with a standard Treet building in Norway, having all details of components highlighted in the designed building, and it is concluded that the designed is more resilient and sustainable.

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DECLARATION OF COMPETING INTEREST

None

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