TEAM SHUNYA
Building a sustainable future

Durability & Resilience

U.S. DEPARTMENT OF ENERGY
SOLAR DECATHLON

Jury Documentation

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Introduction

Mumbai is a city on the coastline well-known for its rain and skyscrapers. One of the cities with the most significant population growth in the world is not without issues and dangers. A 200 mm of rain in a single day is not an uncommon monsoon. Hazards due to mistakes, such as fires, have also impacted Mumbai. In 2022, a major fire broke out at one of the 61-storey buildings. So, we had to make the structure reliant and to be able to provide seamless comfort to the occupants in case of a crisis. For example, the building might have to cope with a day's blackout, or a water blockage, while withstanding strong monsoon winds and heavy rains. We distributed every aspect of a risk with the following concept.

Any engineering design analyses the conditions it would be facing against. The following approach is used to design various components of the house.

- Assess risk - Conditions the structure can face and measures taken to mitigate the possibility of the disaster
- Withstand - Surviving in face of a crisis with backups.
- Resist - Fighting the hazards and standing strong at the end of the day.
- Mitigate - Optimizing the available resources to survive longer.

Assess Risk

The risk to durability lies in many ways, including triggered by natural and human-induced or a combination of both disasters. Human-induced factors can significantly aggravate the adverse impacts of a natural disaster.

Natural Hazards

The widely accepted classification system used by the Disaster Information Management System of DesInventar classifies disasters arising from natural hazards into five major categories (Des Inventar 2016):

1. **Geophysical:** Geological process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.
2. **Hydrological:** Events caused by deviations in the normal water cycle and/or overflow of bodies of water caused by wind set-up
3. **Meteorological:** Events caused by short-lived/small to meso-scale atmospheric processes (in the spectrum from minutes to days)
4. **Climatological:** Events caused by long-lived meso- to macro-scale processes (in the spectrum from intra-seasonal to multi-decadal climate variability)
5. **Biological:** Process or phenomenon of organic origin or conveyed by biological vectors, including exposure to pathogenic microorganisms, toxins and bioactive substances that may cause loss of life, injury, illness or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage

Out of the above 5 Hazards, we haven't considered climatological hazards as they have a very low probability of occurrence during the life of the house's structure.

Table 1 - Natural Hazards

Hazard	Occurrence	Risk mitigation method
Meteorological Hazard		
Heat Wave	Once in five years	Structure Air conditioned and well ventilated.
Cyclone	Once in two years	Structure designed to take wind loads as per IS 875 Part 3 considering the additional factor for cyclones.
Geological Hazards		
Earthquake	Once in twenty years	Structure designed as per the IS 1893:2016 to take seismic loads for Zone III as per the Indian Seismic Zones
Hydrological Hazards		
Flood	Once in five years	Plinth 0.45 m above ground. Storm water drainage near the site.
Landslides	Once in five years	Site not in a landslide prone zone. Raft footing over soil, to ensure prevention of differential settlement.
Biological Hazards		
Covid-19 outbreak	Once every year	Measures for ventilation and isolated spaces in the house.

⚠ Human-Induced Hazards

The National Policy on disaster management notes that with the rapid urbanization and industrialization, the chances of risks due to human induced hazards have increased. The hazards which are most likely to occur and the measures to mitigate them are mentioned in Table 2.

Table 2 - Human Induced Hazards

Hazard	Risk mitigation method
Electrical	
Short Circuits	Electrical Circuit Breakers
Electric Outage	Battery Storage System
Plumbing	
Water Leak	Using BIM and agro-waste based boards in house provides ease in locating pipe leakage to the precision of mm and fixing it.
Choking of pipes	Layout design of plumbing in Revit to ensure least number of joints in the house.
Envelope Materials	
Fire	All materials ensured to have a fire resistance of at least 2 hours
Degradation	The materials that can withstand the climatic conditions of Mumbai are only chosen.

Withstand

Assessing the risk cannot be enough if you cannot withstand it during the hazard. To withstand these conditions, we need backups for food, water, and electricity. The building also has to stand up to the typical climatic conditions which weather the structure and have long-term effects. This section describes the strategy to withstand the conditions the building will face during its lifetime.

Life of the structure, components and services

The building's structure is created with a 50-year design life in mind. (IS 800: 2007) The loading and analysis are done such that, with only minor upkeep, the structure won't degrade and can endure the forces of nature to stand tall and strong for the next 50 years.

The building envelope and the services have a lesser design life and may need major upgrades after 25 years of operation.

The **Error! Reference source not found.** mentions the life expectancy of the majorly used systems in the building.

Table 3 - Material/Component Life Expectancy

Material/Component	Life Expectancy (years)	Remark
	Structure	
Steel	50	As suggested by the IS codes for the residential building
	Wall Assembly	
Ecoboard: An agro-waste based material for wall panels	30	Although replacement suggested every 25 years
Glass-wool insulation	Building's lifetime	
Fibre Cement Board: For exterior walls	50	Used for exterior panels due to high durability
	Generation System	
Solar Panels: Mono PERC Bifacial, Half-cut Panels	25	Degradation overtime will reduce performance
Inverter	10	Future-proof to work with Lead-Acid or Li-ion batteries
Battery: Lead Acid	4-5	Using Li-ion will increase the lifetime to 8-10 years
Plumbing		
PVC Pipes	100	Replacement suggested every 40 years to avoid pipe decay
Water fixtures	Building's lifetime	Might need maintenance

Solar Electricity Generation

The generation system has a hybrid design which allows battery storage and bidirectional flow of electricity with the grid. The system is equipped to withstand grid failure and annual weather patterns.

Grid Failure

Battery storage allows survival through short-time power cutoffs from the grid. The battery storage capacity is enough to accommodate the night-time energy consumption of the house.

Solar PV can power utilities during the daytime and charge the batteries for the coming night. Reducing loads by disabling the power to non-essential loads can prolong the backup duration in case of less generation from solar PV due to weather conditions.

Annual Weather Patterns

The Indian climate has around four months of monsoon period during which the solar PV generation cannot fulfill the daily energy demand of the house. The energy required to meet the demand is then taken from the grid, and the excess generation during the summer and winter seasons is exported to the grid to offset the consumption on an annual basis.

Water Cutoff

Mumbai has a tropical and wet climate. During monsoons, it rains heavily. We collect this water, filter it, store it and use it which is good enough for water requirements of the house except drinking and cooking. We installed two leaders on the rooftop with the slope to collect all the rainwater. Leaders will lead the water into the pipes (gutters) connected with rainwater harvesting filters. Our catchment area is more than 500 sq ft. to provide enough water to sustain water cutoff for a month.

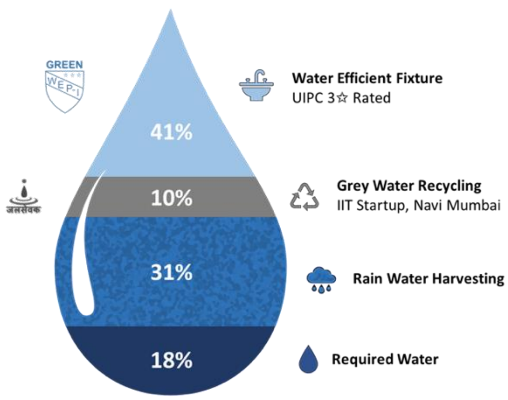


Figure 1 - Breakdown of Water Use

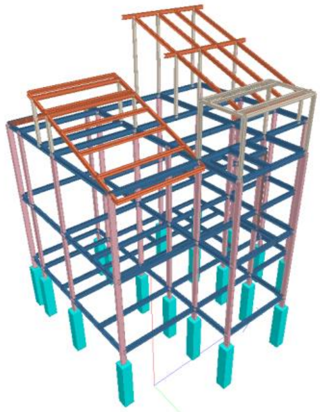
Resistance

In addition to withstanding the risk, it must resist any adversities. The structure must resist the winds, earthquakes, electric lightning, fires, and poor air conditions. How the design considers all these parameters is covered in this section.

Earthquake

The structure has been analyzed by Equivalent Static Method (ESM) and Response Spectra Method (RSM) as per IS 1893:2016. Mumbai falls under earthquake Zone III for India, with the highest intensity being Zone V and the lowest being Zone II. Hence, the region has a moderate probability of an earthquake occurring. The structure's design considers soft soil as defined in IS 1893 (Part 1) Table 4. The importance factor considered for the building is 1.0 as per Clause 7.2.3 in the Indian Standards. The moment frame system is a steel building with an Ordinary Moment Resisting Frame (OMRF) for lateral loads.

The seismic weight of the structure considers all the dead load and 25% of the live load when less than 3 kN/m^2 and 50% of the Live Load when more than 3 kN/m^2 on it. The time period of the structure for the first mode is 0.77 seconds, i.e. a frequency of 1.298 Hz. The first 100 modes' shapes were considered leading to a contribution of more than 99% for the Response Spectrum Analysis of the structure. The Response Spectra considered is the design spectrum mentioned in Clause 6.4.2.b. The storey drift is limited to 0.004. The max displacement in the structure is 29.87 mm. The max allowed displacement for the structure in earthquake is 42.2 mm.



To summarize, the structure will survive the shaking of the earth without any loss of life. The structure also considers the approach of strong columns and weak beams to ensure that the building doesn't collapse on the occupants. The ductility of steel and this approach gives enough warning for occupants to reach safety, in case the structure cannot withstand the disaster

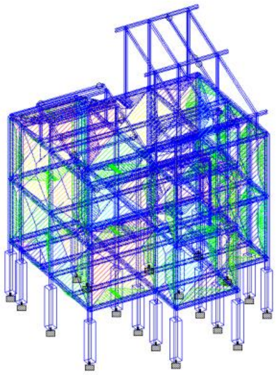
The places where landslides occur are around 20 kms from the site. To ensure that such an event doesn't lead to loss of life, the structure is built on a raft foundation which prevents differential settlement and provides a uniform distribution of load on the soil.

Wind

Since two cyclones have hit Mumbai in the last four years, wind is one of the major considerations in the structure analysis. Hence, wind loads turned out to be critical for the structure as it is made of steel which is lighter than RCC. The analysis parameters are summarized in the Table 4.

Table 4 - Wind Analysis Parameters

Parameter	Value	Remark
Basic Wind Speed	44 m/s	For Mumbai
Topography factor	1.15	Accommodates effect of cyclones in Mumbai
Risk Coefficient	1.0	For 50 years of structure's life
Terrain category	2	Well-scattered low-height obstructions
Pressure coefficients	Clause 7.3	



The loads are considered as per IS 875 (part 3): 2015. The maximum displacement in the structure due to the winds is 19.96 mm. The max allowed removal of the structure for wind loads is 21.1 mm. The structure was optimised at places to ensure effective utilisation of the sections. The sections were designed in conjunction with the constraints provided by the envelope.

To summarize, the structure will resist the winds for the upcoming fifty years without much trouble.

Electric Safety

To ensure occupant safety from electrical shocks, we've installed earthing for solar PV panels, inverters and the mains supply of the house. Circuit breakers for each phase as well as branch circuits are installed to avoid any damage from surge in currents. A lightning arrestor is also installed on the roof to avoid any damage from a lightning strike.

Fire

The house is designed to alert, withstand and mitigate most fire hazards. A fixed heat smoke sensor will be used for the kitchen and ultraviolet flame detectors will be used for the other areas. These devices will alert the users in case of a fire.

Table 5 - Fire resistance of Materials

Material	Duration for withstanding fire
Fiber Cement Boards	Class I - BS 476 Part 7
Ecoboard	2 hours
Metal deck	2 hours
Structural Steel	2 hours

All the materials are selected to resist fires for up to 2 hours. This gives the occupants a chance to escape once the sensors alert them in case of a fire that cannot be mitigated within time. A retractable ladder is provided to ensure that the people on the first floor or the roof can exit the building as fast as possible. Also, the two ways to enter the house on the ground floor can serve as multiple exits.

Small flames or those detected earlier can be eliminated using the dry chemical fire extinguisher which is kept at an easily visible and accessible location. The following table sums up the fire resistance capabilities of materials in the house.

Mitigate

There is a need to optimize the use of resources in daily life to better handle risks in their availability. Here, we describe methods we've adopted to ensure the effective use of the resources and planning for potential threats.

Automation

In order to save energy, we are also implementing automation systems to turn off the utilities like the lights and HVAC when not in use. The system contributes to long-term energy savings since it uses less energy to run the utilities than it does to monitor the presence of inhabitants.

HVAC

Based on the climatic conditions of Mumbai, it has a high latent load energy throughout the year compared to the sensible load cooling energy. Driven by this fact, the system is designed to handle the latent and sensible load separately to ensure controlled comfort conditions throughout the year. A fan coil unit at higher chilled water temperatures for better COP handles the sensible load. The latent load is handled by a liquid desiccant-based dehumidification system with high COP developed for better and quicker control of the relative humidity levels of the room.

Occupant health and safety

All these facilities, comfort and sustainability are for the interaction of nature and the occupant. The occupant's safety is critical in case of any disasters. The structural design ensures that there is no harm to the occupant in case of any disaster. The services in the building are to ensure that there are backups in case of any disruptions.

Air quality, especially CO_2 levels, is critical to the occupant well-being (Jacobson et al. 2019). We've implemented an automated ventilation system to monitor and maintain the CO_2 levels in a given room. The system triggers when the CO_2 levels are above a room-specific threshold and turns on the exhausts in the room.

Simple but effective features are provided in the house to take care of occupant's health. A first aid box in an accessible and visible position is provided in case there are any minor injuries. The railing is provided over the staircase, balcony and parapet over the roof to ensure no child falls from greater heights. The automation app offers a safety feature to send a message to the emergency contact.

Passive Strategies

Orientation for Thermal Comfort and Ventilation

The house is oriented such that the most used spaces get diffused sunlight from the north, creating a play of light and shadow. Bedrooms are placed on the west (predominant wind direction) to harness the wind for passive cooling.

The bedroom windows are placed on the predominant wind direction's western facade. Stack ventilation design in the living room creates a differential pressure between the top and bottom of the building to allow hot air to rise and escape through vents at the top while drawing in cool air from below. Moreover, the natural ventilation is enhanced by using fans to increase airflow.

Natural Lighting

Open floor plans with fewer walls and partitions help natural light penetrate deeper into the building. High-performance windows are placed strategically to maximise natural light while minimising heat gain. The windows are equipped with shading systems to control the light entering the building. The diffused light entering the house is maximised by placing most of the large windows on the north.

Wall Assembly for Thermal Comfort

Eco-board, an agro-waste-based material for wall panels, and glass wool are used as a wall assembly to enable thermal comfort, hence reducing energy consumption of mechanical cooling systems.