A STUDY OF LIFE CYCLE ENERGY ASSEMENT OF A MULTI-STORIED RESIDENTIAL BUILDING IN PUNE REGION

Ar. Shraddha Narvekar[1], Prof. Sudhanshu Pathak[2]

[1]Research Scholar, S.Y.M.arch Dr.D.Y.Patil College of Architecture
[2]Assistant professor, Department of Civil Engineering,D.Y.Patil College of Engineering Akurdi,Pune

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Abstract - *In recent years climate change has become a growing concern all over the world, and because of this it has become a necessity to monitor the carbon emission in various industries. This study focuses on life cycle analysis of a 12 year old residential building in Pune. It focuses on the energy utilized during its construction, the energy utilized during its current phase which can be deemed as operational energy and its demolition energy during its end of life cycle. As the building is almost a decade old it lacks many environment norms which are currently in use today. The primary aim of this study is to calculate the total energy expenditure of the residential building and provide a definitive carbon foot print of the same. This study also focuses on providing energy efficient solutions to reduce the carbon footprint and its dependency on natural resources*

***Key Words*: Carbon Footprint, Energy efficient, Eco-friendly, Climate Change, Embodied Energy, Residential building, Pune , Life Cycle Assessment, Construction Energy, Operational Energy, Demolition Energy.**

1. INTRODUCTION

The construction industry is known to be the largest consumer of natural resources in the world. It is also a major contributor in the emission of greenhouses gases. These GHG are an addition to the ongoing crisis of global warming. Out of total energy generated worldwide 39% of the energy is consumed by the construction sector and it also emits 30% of carbon dioxide.(1). The materials used during construction such as steel cement metals etc require tremendous amount of natural resources for their production. The energy demand for production of such materials is very high. In recent years the construction industry experienced an increase boom due to rapid urbanization.

Various smart cities schemes are being developed by the government to accommodate the influx of people migrating to cities due to various job opportunities, comfortable lifestyle and easy access to many facilities. According to a survey done from 2016 to 2020 there is a demand of 1.98 million houses in the low income group whereas the supply is only about 25000 unit (statista). Due to this there has been an increasing demand in construction materials and also generation of waste on construction sites.

As the building has 3 phases such as construction, operation and demolition phase. It is observed that most of the energy is consumed in the operation phase of the building. Therefore it has become a necessity to develop and implement measure which can result in effectively reducing the carbon footprint of the building.

1.1 Need of this study

Climate change and global warming are manmade calamity that the world is facing today. Carbon emission across the globe has been increasing at an alarming rate. It has become a necessity to regulate the carbon emission and GHG. Therefore it is a need of hour to define and reduce the carbon foot print of the building through Life cycle analysis considering its maintenance period of 15 years. As there have been various studies conducted on carbon footprint across various parts of India. No study on carbon footprint has been conducted in or around Pune region. This study focuses on multi storied residential building in Pune region. This study analyses the life cycle of the residential building and also derives the carbon footprint of the same and provided solution to reduce it.

1.2 Aim

The researcher focuses on life cycle assessment of G+7 residential building in Pune area and the total energy expenditure during it life cycle and maintenance also providing eco-friendly to reduce the derived carbon footprint

1.3 Objectives

•To analyses various phases of a residential building
•To study the energy usage in various life stages of the residential building
•To derive carbon footprint of a residential building
•To provide effective energy efficient solutions

1.4. Research Questions

1. How much energy is utilized during the construction phase?
2. What are the embodied energy of the building materials used?
3. What is the operational energy of the building?
4. What is the demolition energy?

1.5. Methodology

The methodology is divided into 5 categories. The first category deals with preliminary analysis of the research topic. The second category deals with literature review from various related published research papers. The third category deals with data collection from the live case study. The fourth category analysis the data collected from the case study and provides findings. The fifth category provides solutions and proposals. The last category concludes the entire research and defines further scope of study.

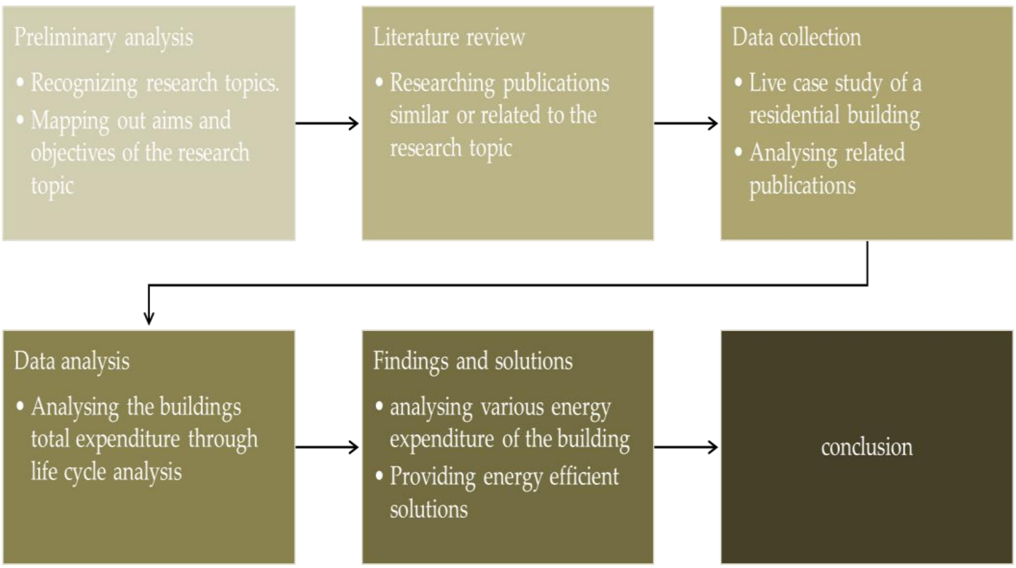


Fig -1: Methodology flow chart

2. LITERATURE REVIEW

2.1 Life Cycle Assessment Stages

Life cycle assessment of a building is divided into 4 stages which is further classified into various sub stages. These stages are developed and provided by International Organisation for Standardisation (ISO) in ISO 14040 and 14044. There are 4 stages in life cycle assessment of a building they are

- Product stage - A1-A3
- Transportation stage –A4-A5
- Operation stage-B1-B7
- End of life stage – C1-C4

As shown in figure 2 the product stage includes from the extraction of raw materials, transportation of materials to manufacturing plant and manufacturing of materials required for the construction of building. This stage also included transportation of manufactured materials to required construction site.

The operation stage includes the total energy usage of during its life span for heating cooling and for various electrical appliances. It also included the repair and maintenance of the building for every 15 years.

The end of life stage includes the energy required for demolition of the building, transportation of waste materials, processing of waste materials and disposal of materials which cannot be recycled.

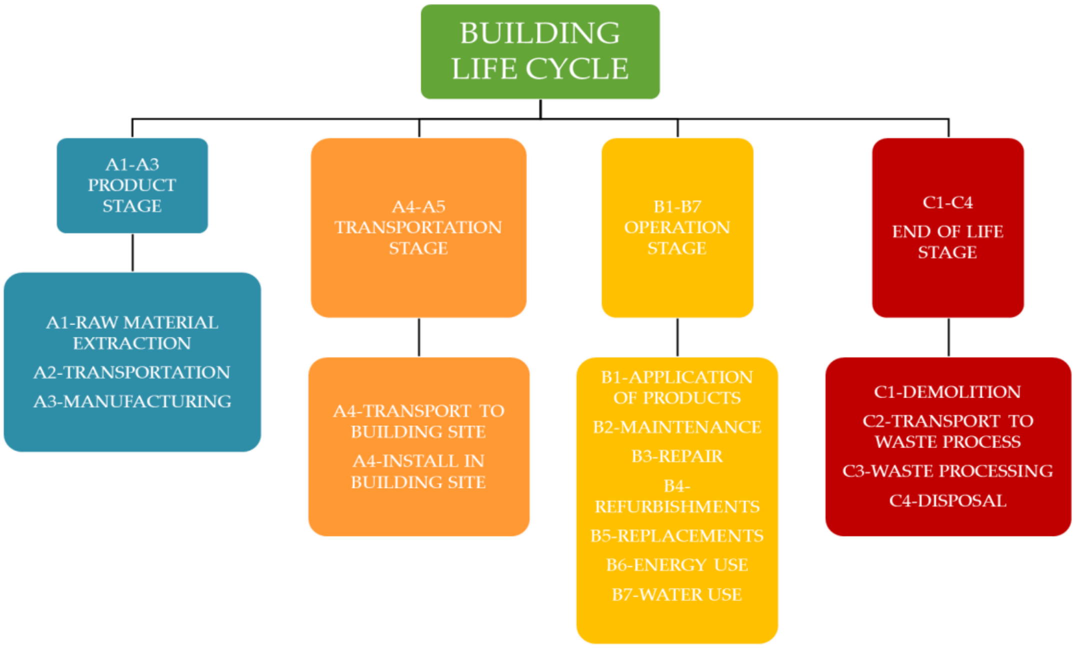


Fig -2: Life cycle assessment stages

2.1.1 Ecological footprint (EF)

The concept was developed by Mathis Wackernagel and William Rees almost two decades ago. It is a summation of complete energy usage of a building during its life time. It is also an assessment of the impact of a building in biosphere which determines the EF of a building on the basis of its consumption of natural resources, emission of GHG , water usages etc.

2.2 Life Cycle energy of the Building (LCE)

LCE is defines as the total energy expenditure of the building during its lifetime. The summation of the energy utilised during construction phase operation phase and demolition phase amounts to the total energy expenditure of the building.the following equation represents the formula for calculating LCE

$$LCE=CE(EE_{(I)}+EE_{(R)}+TE)+OE+DE$$

LCE = life cycle energy

CE = construction energy

EE $_{(i)}$ = initial embodied energy

EE $_{(r)}$ =recurring embodied energy

OE = operational energy

DE = Demolition energy

Construction energy (CE) is further subdivided into 2 parts which is $EE_{(i)}$ initial embodied energy $EE_{(r)}$

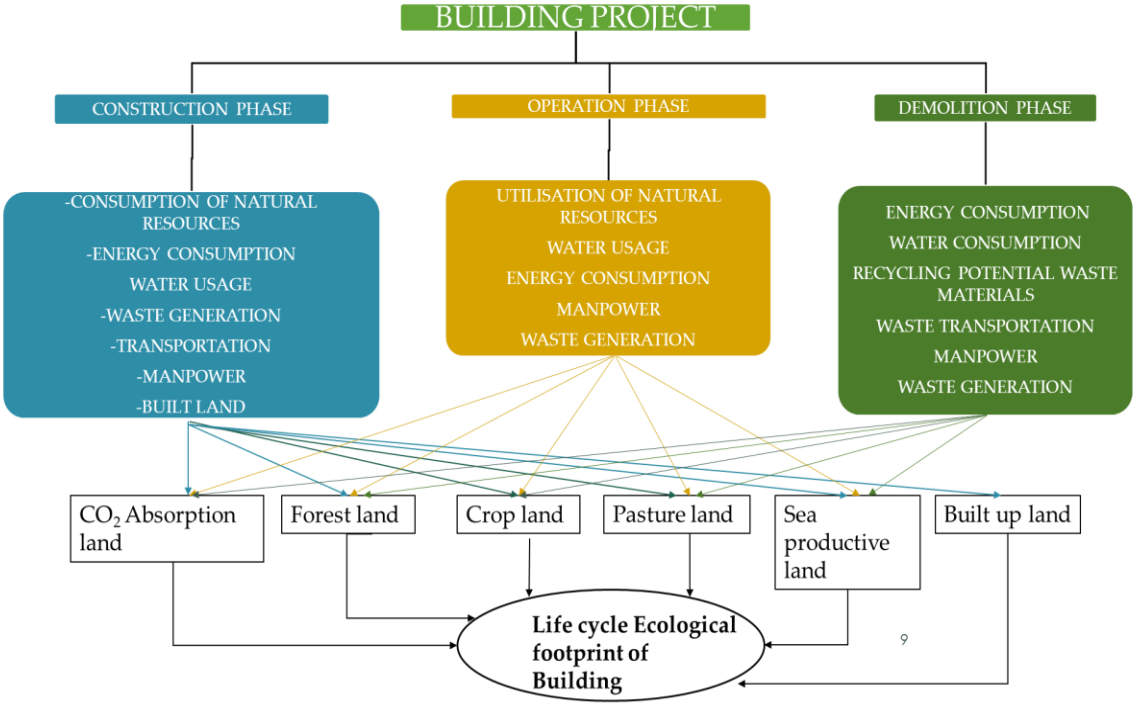


Fig -3: life cycle ecological footprint of the building

2.3 Embodied energy of building materials (EE)

Embodied energy can be summarized as the total energy expenditure necessary for various processes like extraction, processing and manufacturing of building materials. During the various processes which are required to produce building materials large amounts of energy is required because of the energy consumption it generates tremendous amounts of CO2 which results in the emission of various GHG. Therefore the embodied energy is considered as the indicator of the total environment impact of the building materials

The EE is further subdivided into 2 types namely

2.3.1. Initial Embodied Energy ($EE_{(i)}$)

The energy which is utilised during the initial development phase of the building is known as Initial embodied energy. Following equation can be used for calculation the initial embodied energy

$$EE_{(i)} = \sum m_{(x)} M_{(x)} + E_{(c)},$$

where $M_{(x)}$ = energy content of the material per unit quantity;

$m_{(x)}$ = total quantity of building material used ;

$E_{(c)}$ = energy utilized at site for construction of building ;

$EE_{(i)}$ = building initial embodied energy.

2.3.2. Recurring embodied energy ($EE_{(r)}$)

It is the energy which is utilised for repair and maintenance of the building during its life span. As building materials have a life span which is less compared to the life span of the building. The following equation is used for calculating recurring embodied energy

$$EE_{(r)} = \sum m_{(x)} M_{(x)} [L_{(b)}/L(m(x)) - 1],$$

where $L_{(b)}$ = building life span;

$EE_{(r)}$ = recurring embodied energy of the building;

$L(m(x))$ = material life span.

Sr.no	Description	Embodied energy (mj/kg)		
		Indian data (BMPTC, 1995; Reddy et al. 2003; Shukla et al. 2009)	LCE:inventory Carbon and energy (Hammond and jones 2008)	Base data
1	Cement	5.9-7.8	4.6	6.85
2	Sand	0.1-0.2	0.1	0.15
3	Coarse aggregates	0.4	0.1	0.4
4	Cement blocks	0.745	0.81	0.745
5	Rebar	28.2-42	24.6	35.1
6	Ceramic tiles	3.33	9	3.33
7	Putty	-	5.3	5.3
8	Paint	144	68	144
9	Pvc	104-108	67.5	106
10	Glass	25.8	15	25.8

Table -1: Embodied energy of various building materials

2.3.3 Transportation stage (TE)

The energy consumed while transporting required materials for construction of a building from various places. Transportation energy can be calculated by the given equation

$$TE = DC \times FC$$

Where, DC = total distance travelled to and fro for hauling and delivering of construction materials from manufacturing plant to site,
FC =consumption of fuel in liters.

2.4 Operational energy (OE)

It is the energy which is consumed for heating, cooling and operating of machines in the building. Operational energy is estimated by the given equation

$$OE = E(OA) \times L(b),$$

Where,
L(b) = building life span;
E(OA) = yearly operating energy;

2.5 Demolition energy (DE)

It is the energy required for demolition of the building and transportation of waste generated during demolition of the building. The demolition energy can be calculated by the following formula.

$$DE=CE*10\%$$

CE=construction energy.

3. CASE STUDY

India is divided into 5 climatic zones namely Hot and Dry, Warm and Humid, Temperate, Composite, and Cold. The scope of this study is limited to residential building in Pune, Maharashtra. The climate of Pune is hot semi-arid bordering tropical wet and dry. This study is limited to residential building in Pune region where the minimum winter temperature goes up to 8oC from November to December and maximum summer temperature goes up to 42oC from March till June. Monsoon in Pune spans from July to September. The EE, LCE and LCEF of the residential building has been calculated.

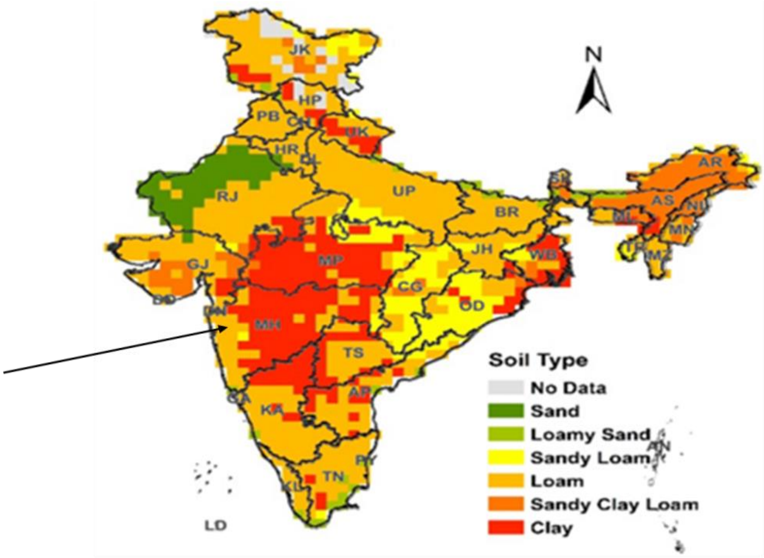


Fig -4: Various climatic zones of India

3.1 DETAILED INFORMATION OF CASE STUDY

PARAMETERS	RESIDENTIAL BUILDING
Age of the building	12
Building occupants	336
No. of flats	84
Area(m²)	8848
Energy Consumption(kwh/day)	550-600
Water consumption (liters/day)	45360
Maintenance time	15
Building Life span	100
Structural Typology	R.C.C

Table -2: Parameters of residential Building

The parameters of the residential building mentioned above has been constructed 12 years ago. The building is constructed using R.C.C technology and the walls have been constructed using AAC(autoclave aerated concrete) blocks. The building consists of 7 floors and the total area of the building is 8848 sq.mt with a deviation of 2%. It has 4 category of flats with different area and room sizes. The building consists of mostly single family occupants. The building lacks major environment friendly technologies which have been used in recent times.

The life span of any R.C.C structure is 100 years. For calculations of construction energy of the building the data was gathered from the builders and the contractor office. The embodied energy of the materials used during construction is also analyzed. Below table provides the transportation details of vehicles used and the total distance travelled by the vehicles for transportation of construction materials from manufacturing plant to construction site.

Building materials	Quantity (W_{mp}/kg)	Number of trips	Total distance travelled	Fuel efficiency (km/lit)	Fuel consumption (lit)
Cement(LDV)	1,56,279	60	1248	7.43	167.96
Concrete blocks(MDV)	78513	25	700	3.25	215.38
Ceramic tiles(LDV)	102752	7	140	7.43	18.84

Table -3: Fuel consumption during transportation

The embodied energy of the building material was calculated from Table No.1. The operational energy of the building is calculated according to the monthly electricity consumption of the residents of the building. Due to Covid-19 pandemic as majority of the work places have a work from home policy so many resident are working from home because of this the electricity consumption and demand has increased in the last 2 years. Before the pandemic the electricity consumption was observed to be lower during the weekdays from 9am -7-pm and the demand increased on weekends. The electricity consumption is observed to be high during summer because of temperature soaring above 400C and was lower in winters.

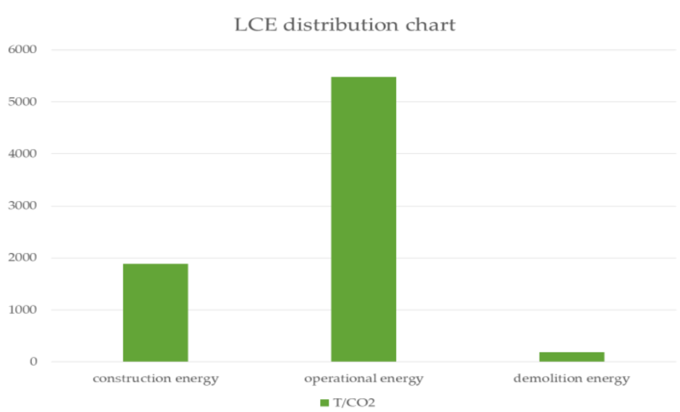
Sr.No.	No.of flats	Monthly electricity consumption(kw)	Total electricity consumption (kw/month)	Yearly electricity consumption (kw/year)
Residential building	84	$200_{(avg)}$	16800	6132000

Table -4: Electricity consumption of residential building

As the buildings age is below 15 years no maintenance has been required so far.

4. RESULTS AND RECOMMENDATIONS

For total LCE the initial and recurring Embodied energy was calculated separately from the above given equations. The operational energy was calculated by the electricity usage of the resident of the building and was multiplied by the no. of years remaining for the end of the building. The below table shows the classification of the LCE of the building.
After the computation of all the energy the ecological footprint of the building was calculated by summation of all the above listed energy which equal to 7555.4 tco2/e which comes around 0.85 tco2/e m2. To reduce the LCE and LCEF of the building the following energy efficient solutions are provided,



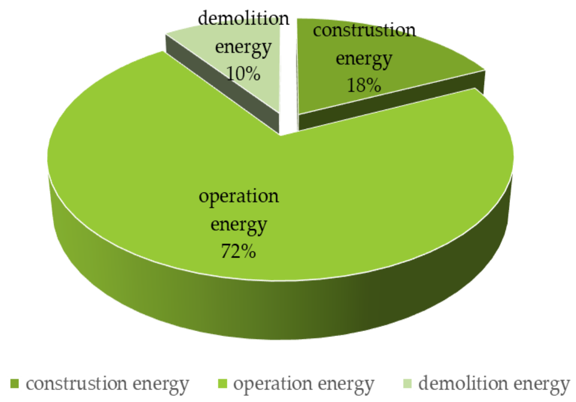


Fig-5, 6: Energy distribution of the building

4.1 INSTALLATION OF SOLAR PANELS

There are various research concerning the reduction of life cycle energy of the building by installation of solar panels for electricity generation. Solar powered water heating technology can also be helpful in reduction of LCE and LCEF. It has been observed from various research papers that ecological footprint per m2 of solar photovoltaic cells is around 0.0694 gha/m2. It is noted that a "Grid connected rooftop solar photovoltaic "can help in reduction upto 60% of the total electrical energy demand of the building. Maharashtra electricity board also is known to provide subsidiary on electricity bills of residential building who have 'grid connected rooftop photovoltaic cells' installed. Flat plate solar collector is the most basic and inexpensive solar water heater to meet hot water demands of residential buildings. This technology can help in significantly reduction of LCE of the residential buildings. Phase changing materials are rapidly growing technological advance building materials which help in reducing the electricity demand of the building all the while maintaining the thermal comfort of the building.

Fig-7: Solar powered water heater

Fig-8: Solar cells

4.2. ENERGY EFFICIENT BUILDING MATERIALS

For reduction of LCE materials with low EE should be used in construction of the building. There are many substitute building materials with low EE which can prove to be an efficient replacement of conventional building materials such as brick, cements, plaster etc. The substitute materials are filler roof slab, lime pozzolana cement (LP) , clay fly ash bricks , prefabricated roofing systems, stabilized mud blocks etc.

Fig-8: Stabilized mud blocks

Fig-9: filler roof slabs

4.3 RAINWATER HARVESTING SYSTEMS.

As the building is more than a decade old it lacks the energy efficient technologies which are in use today one being rainwater harvesting systems. Due to the scarcity of water faced in recent times rainwater harvesting has become mandatory. The water harvested can be used for flushing and gardening purposes. Rainwater harvesting systems reduces the dependency on municipal water supply.

5. CONCLUSION

The research paper is based on a single residential building in Pune. The ecological impact of the building during its entire life span is analyzed in this research paper. Alternative building materials with low EE have been researched and studied in this research paper which can help in reduction of total LCE and LCEF of the building. The following is the summary of this research paper:-

•Installation of Solar panel in the roof top of the building
•Installation of rainwater harvesting systems
•Usage of energy efficient building materials for maintenance of the building.

Reduction in LCE and LCEF has become a necessity in recent times due to climate change and various other factors. LCEA and LCEF can be a value added decision making tool in the construction industry. Ecologically conscious decisions can be made by calculating LCEA and LCEF of a project. Comparison of different materials and their impacts in the environment can be done by the stakeholders involved in the project which can help them decide to select alternative building materials which suits the project as well as the environment. With this research and methods can help reduce ecological impact of materials in environment and can lead towards sustainable development.

6. ACKNOWLEDGEMENT

I would like to thank my guide Mr.Sudhanshu Pathak sir for guidance on selection of topic to framing objectives and refining my project topic. I would also like to extend thanks to the committee member of the residential society of whom the case study was done.

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BIOGRAPHIES

Ar.Shraddha Narvekar. She has completed B.arch in 2016 from Mumbai university.
Currently pursuing M.arch in construction management from Pune University.

Prof.Sudhanshu Pathak.
Is currently professor in Dr.D.Y.Patil College of engineering from last 10 years