Building Information Modeling

Abstract

Building Information Modeling (BIM) has emerged as a transformative technology in the construction industry, revolutionising the way construction projects are planned, designed, constructed, and maintained. This document presents an overview of the benefits, challenges, and opportunities associated with the implementation of BIM in construction project management.

The objective of this study is to investigate how BIM can enhance construction project management processes and improve project outcomes. The study explores the various dimensions of BIM implementation, including its impact on collaboration, information exchange, visualisation, clash detection, cost estimation, scheduling, and facility management.

Key Points:

- BIM Importance

  Conceptualization

  → Design andPlanning

  → Finance

  → Regulators

  → Construction

- Minimise energy consumption

Introduction

When we think of doing any project, with the help of BIM we can see that project in a visual form. Realistic view of that project, we can see how that project will look later, how much it will cost etc.

Building Information Modeling (BIM) is a digital representation of the physical and functional characteristics of a building or infrastructure project. BIM is a process that involves creating and managing digital models of the project's design, construction, and operation.

Steps involved in building information modelling

Conceptualization

Initial stage, the project team defines the project's goals, requirements, and overall design concept. The project stakeholders collaborate to determine the project's scope and objectives.

3D Modelling

BIM starts with the creation of a 3D digital model of the building or infrastructure. Architects, engineers, and other professionals use specialised software to develop a virtual representation of the project. This model includes various elements like walls, floors, doors, windows, and other components.

Data Integration

BIM goes beyond a 3D model by integrating additional information about the building's components. This information includes properties such as dimensions, materials, costs, performance characteristics, and supplier details. The model becomes an information-rich database that can be accessed and utilised throughout the project lifecycle.

Collaboration

BIM facilitates collaboration among project stakeholders by providing a shared platform for communication and information exchange. Architects, engineers, contractors, and other team members can work together on the same model, making real-time changes, identifying conflicts, and coordinating their activities more effectively.

Figure 1: Building planning and Construction

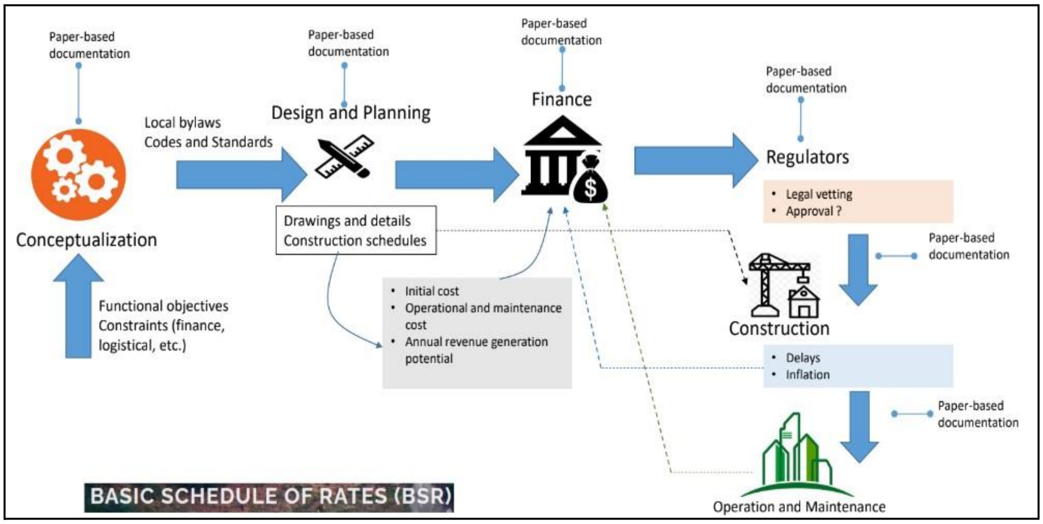
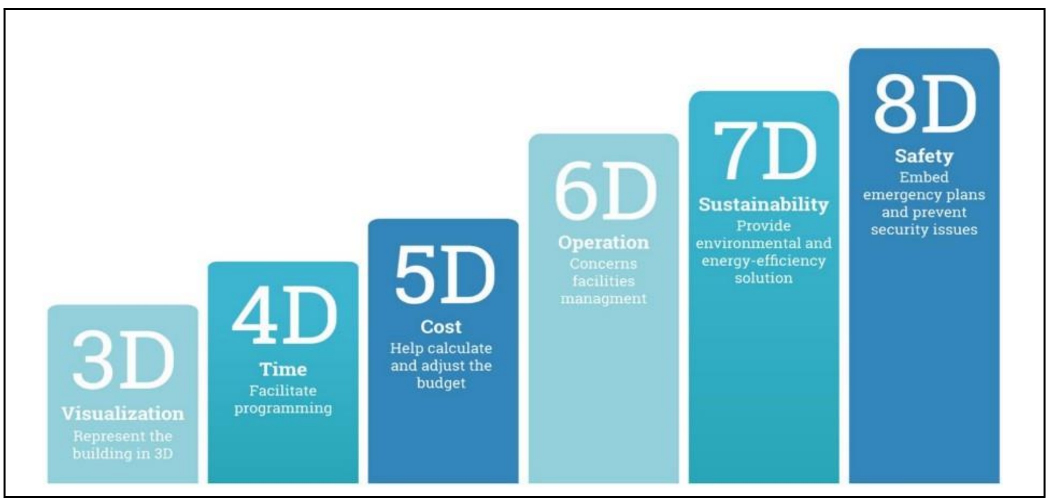


Figure 2: Dimensions in BIM



Analysis and Simulation

BIM allows for the analysis and simulation of various aspects of the project. This includes energy performance analysis, structural analysis, clash detection (identifying conflicts between different building systems), and other simulations that help optimise the design and construction process.

Construction Documentation

BIM software can generate accurate and detailed construction documents directly from the model. This includes plans, sections, elevations, schedules, and other necessary documentation for construction purposes. Any changes made in the model are automatically reflected in the documentation, reducing errors and inconsistencies.

Project Management

BIM can be integrated with project management tools to streamline project scheduling, resource allocation, and cost estimation. By linking the model with project management software, stakeholders can track progress, monitor changes, and make informed decisions throughout the project lifecycle.

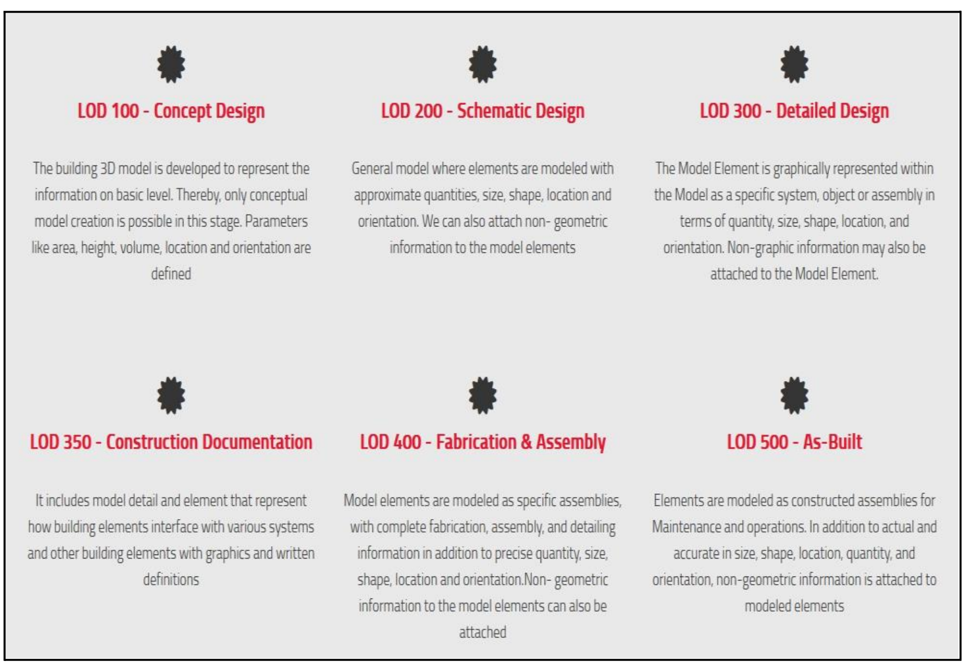
Facility Management

BIM's value extends beyond the construction phase. The digital model and associated data can be handed over to facility managers to support maintenance, operations, and renovations. BIM can assist in asset management, space utilisation, energy management, and ongoing maintenance activities.

Level of Development: LOD

The level of development (LOD) is a concept used in BIM to describe the level of detail and accuracy of the information contained within the model at different stages of a project.

Figure 3: Level Of Development



Key Points

- Revit Software
- The Paris Agreement

  The Paris Agreement establishes a global target to limit temperature increase to well below 2 degrees Celsius. 196 parties have signed the Paris Agreement, including 195 UNFCCC member states and the European Union.

  Each party sets its own national targets for reducing greenhouse gas emissions and regularly reports on its progress.

- BS6 Engine

  With the increase in the level of pollutants in India's metropolitical cities, the Central Government has decided to strictly guide the automakers to change themanufacturing of vehicles suitablefor the Bharat Stage 6 emission norms.

  The BS6 engine will meet the standards to reduce NOx and PM levels and will be able to bring down the sulphur level in the atmosphere.

  This stage will be restricting the emissions from the tailpipe to 1.0g/km of CO. The working of BS6 is mainly based on Selective Catalytic Reduction units.

CARBON FOOTPRINT

Carbon footprint refers to the total amount of greenhouse gases, specifically carbon dioxide (CO_2), emitted directly or indirectly as a result of human activities or A carbon footprint is a measure of the impact our activities have on the environment, and in particular climate change. It relates to the amount of greenhouse gases produced in our day-to-day lives through burning fossil fuels for electricity, heating and transportation etc.

To reduce your carbon footprint in daily life, focus on energy efficiency by using LED light bulbs, energy-saving appliances, and renewable energy sources like solar panels. Opt for walking, biking, or public transportation instead of driving, and choose fuel-efficient or electric vehicles when necessary. Practice water conservation, adopt a sustainable diet with reduced meat consumption, and manage waste through recycling and composting. Consider the environmental impact of your purchases, travel sustainably, and raise awareness about climate change and sustainable practices in your community.

Website: [Carbon Footprint Calculator](https://www.carbonfootprint.com/calculator.aspx)

https://www.carbonfootprint.com/calculator.aspx

In BIM, the concept of carbon footprint refers to the assessment and management of a building's environmental impact throughout its lifecycle, particularly in terms of greenhouse gas emissions. BIM can help designers, architects, and stakeholders make informed decisions about energy efficiency, material selection, and overall sustainability, which can help them evaluate and reduce a building's carbon footprint.

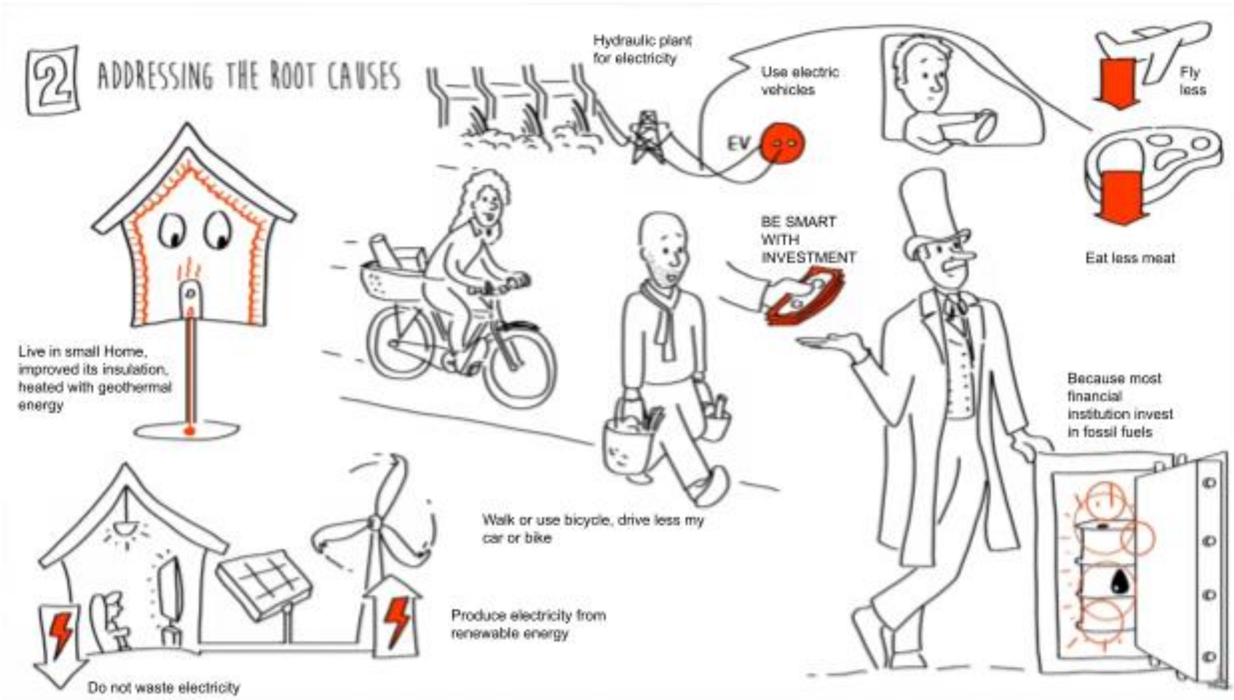
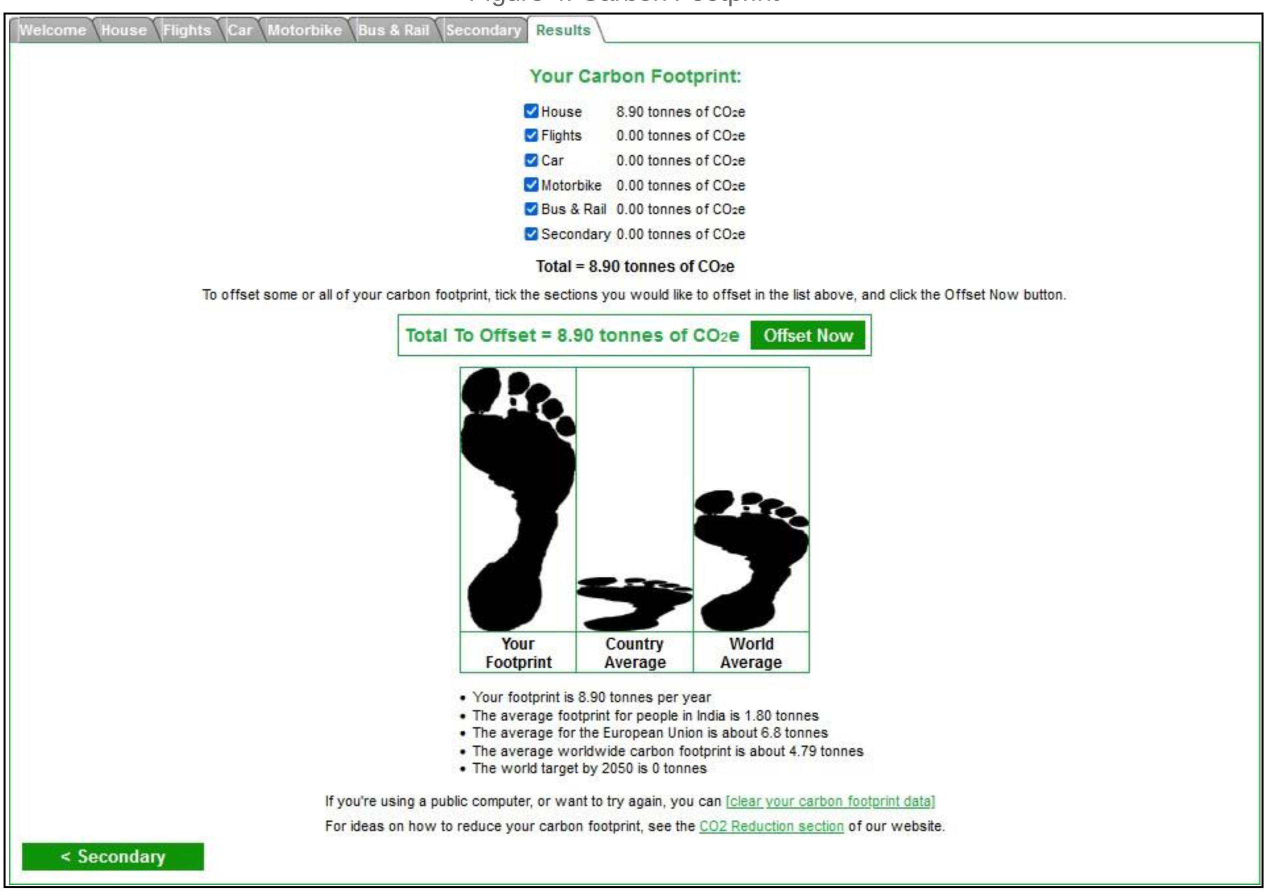


Figure 4: Carbon Footprint



Bricks of BIM from 2008 to 2022 (Case Studies India)

Phase 1: 2008

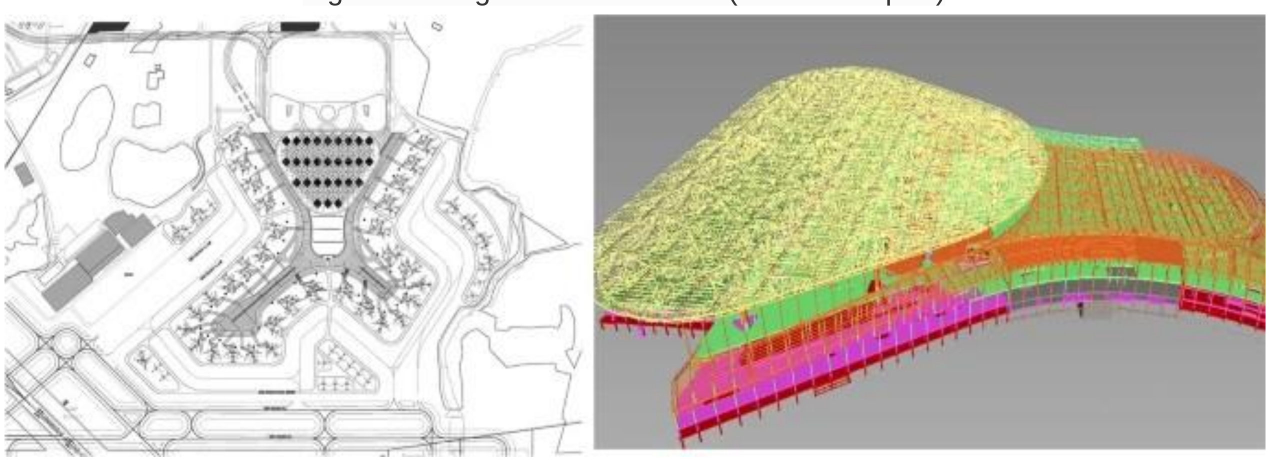
Mumbai airport: April 2008 – December 2014

The Excelize team was entrusted with the challenge of showcasing the benefits of BIM adoption for coordination. A Proof-Of-Concept (POC) was conducted for an area of 5000 sq ft. The 2D drawings provided as input had missing information for building the model. If these were used for construction, there would be multiple Request for Information's (RFI)generated, it would require a lot of rework at site, decisions would have to be made on the spot which would not be recorded. and clash detection was done through the BIM model. This resulted in coordinated 2D drawings from clash free models, which was an eye opener for the D/B contractor to adopt BIM for the entire project.

Challenges:

- Clash free areas and models were produced which the contractors' team was not capable of viewing. Lack of trained staff, infrastructure (hardware/software) and resistanceto accept change were some of the barriers to implementation.

Figure 5: Image from BIM model (Mumbai Airport)



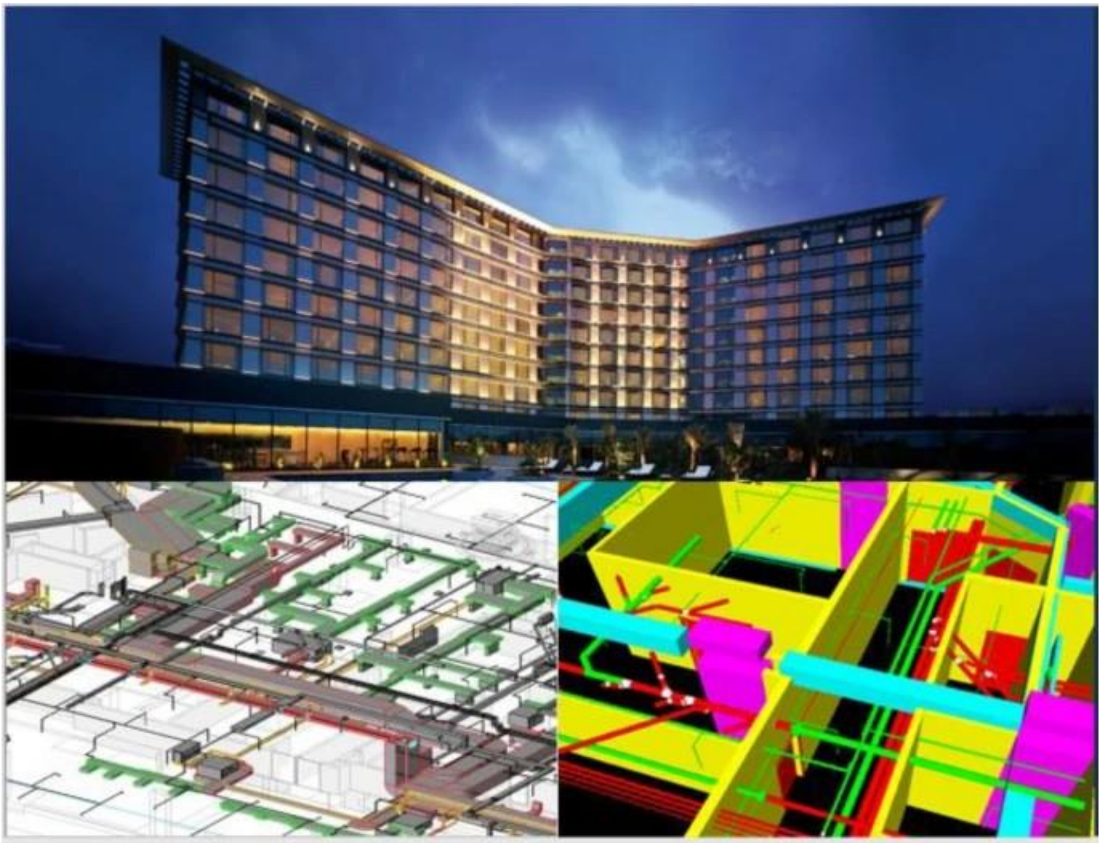
A leading group of hotels: Feb 2012–May 2012

Team Excelize demonstrated the value of BIM models through a presentation. The ability to visualise the entire space in 3D, to plan the services routing more efficiently, identify clashes early in the design process.

Challenges:

- Excelize had to convince the clientteam to adopt BIM due to the lack of a contract that identified the deliverable and the lack of a team to review and utilise the information shared by the BIM team. The project site was in Bangalore and the client was not equipped to view models, so Excelize had to appoint a coordinator to visit and view the BIM model.

Figure 6: Images from BIM model and rendering (Leading Group of Hotels)



Phase 2: 2014–2018

JIO world: 2014

BIM Modelling services were sought by a leading telecom giant for the construction of international exhibition and convention centre. This project coordination would have been a massive challenge if BIM was not deployed. Roles and responsibilities of all stakeholders were clearly defined when related to BIM implementation Hybrid model of on-site and off-site team helped during the initial stages with overcoming the reluctance for remote coordination Principal contractors used the model for construction sequencing and planning.

Challenges:

- A large-scale project which involved multiple activities at same time, managing these activities was challenging.
- Project needed to work with a big team and resources for meeting the project timelines managing the big team was a challenging task.
- Onsite and offsite team were involved in coordination and implementation the coordination between the team was challenging
- This was unique and one of the biggest projects with mixed use design, multiple designers and consultants were involved in the project. To get timely resolution fromthe consultant was the biggest challenge for coordination.

Figure 7: Images from BIM model and rendering (Leading Group of Hotels)

Campus for a large IT services company: 2015

TCS, an IT giant, required BIM support for setting up 10 campuses at 4 locations: Nagpur, and Mumbai. There were 2 BIM consultants working on this project and hence, it was mandatory for the project team to set up standards. Bhubaneshwar, Thiruvananthapuram, No BIM execution plan was set up for these projects though.

Challenges:

- The design was evolving as the construction was progressing at site.The design coordination had to be repeated with every change and this affected the Mechanical, Engineering,Plumbing (MEP) design.
- BIM models were not used to generate the 2D. It was a 2D to 3D effort, which was the reverse of the usual approach which made it more cumbersome.
- The material specifications were not always available to generate the BOQ from the model for all items
- Site changes on materials resulted in consumed quantity not matching tender quantity or BIM quantity as estimated in the plan (specifications had M30 grade concrete and so did the BIM model. Site team substitutedwith M35 which resulted in quantity mismatch).
- Transparency that the BIM model brought was not accepted by the contractor as all information relatedto materials was clearly visible to allteam members.
- On-site coordinator took around 6–7 months to feel included as a part of the team.

Figure 8: Image from BIM model

Phase 3: 2017–2018

New airports being built in India have RFPs asking for BIM Modelling services for design coordination and extraction of quantities. Civil Aviation is an important part of India's transport infrastructure, and the Prime Minister has launched India's biggest international airport at Jewar, which will serve 1.2 crore passengers a year and cost Rs 10,050 Cr. BIM services are being requested for faster delivery and other benefits.

Scope of Work:

The scope could be as below,

- BIM model for architecture, structure, services, baggage handling, landside and airside services, site, landscape, site utilities, interior fixed furniture
- Extracting Bill of Quantities (BOQ) from clash free design model
- Bill verification for the BOQ from model
- 4D construction simulation
- 5D Cost Management
- CAD 2D output drawing from clash free Models
- Asset Lifecycle Information Management
- Dashboards and reporting to management
- On-site BIM coordinators

Phase 4: 2020–2022

Nagpur Metro: 2016–Ongoing

At Nagpur Metro, now MAHA Metro, a 5D BIM digital platform has been implemented since 2015. 5D BIM also referred to as five-dimensional building information modelling enables extraction or production of fully valued invariable project constituents via a virtual model.

Maha Metro is the first organisation in the country to implement 5D BIM project visualisation. 5D BIM is a digital project management concept that integrates many softwares seamlessly and employs 5D BIM to accurately predict outcomes and timelines. This unique system has enabled Maha Metro to control quality, cost and time rather tightly. The Maha Metro project has achieved construction excellence, first converting future physical works into a prior virtual reality and then re-transporting it to the reality of the physical work. Such an amalgamation of convergence of physical and virtual reality in project management is unprecedented in the country, either in government or the corporate sector.

5D BIM can help reduce rework, coordination problems, documentation errors, claims, paperwork, time and cost overruns, and lifecycle costs in the construction industry by reducing rework, coordination problems, communication, documentation errors, claims, paperwork, time and cost overruns.

Figure 9: The digital platform architecture

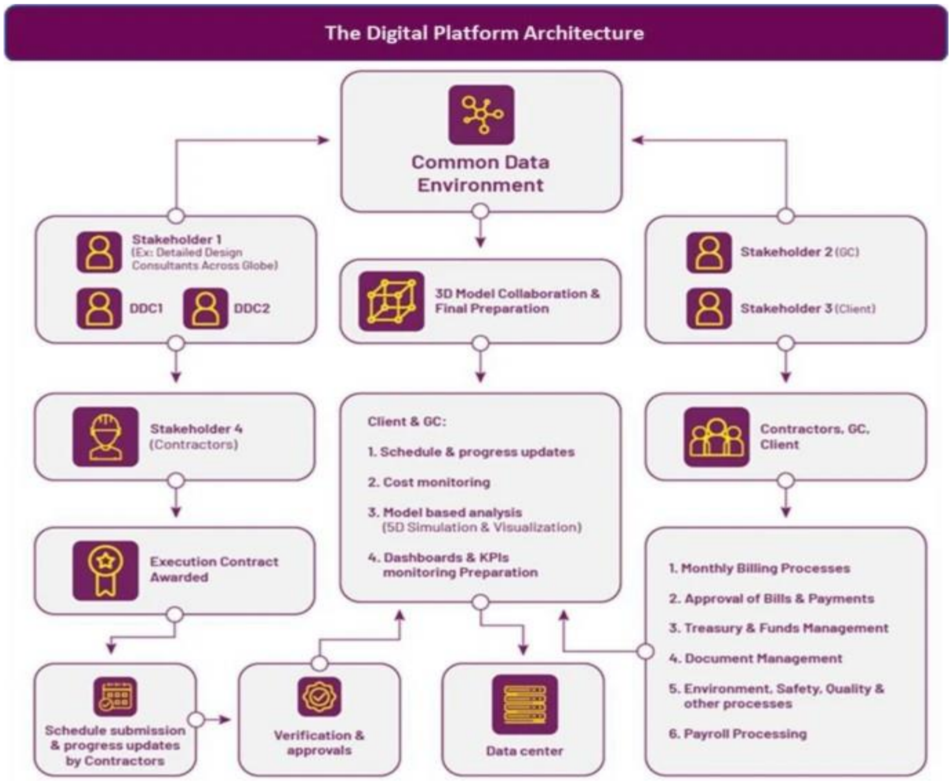
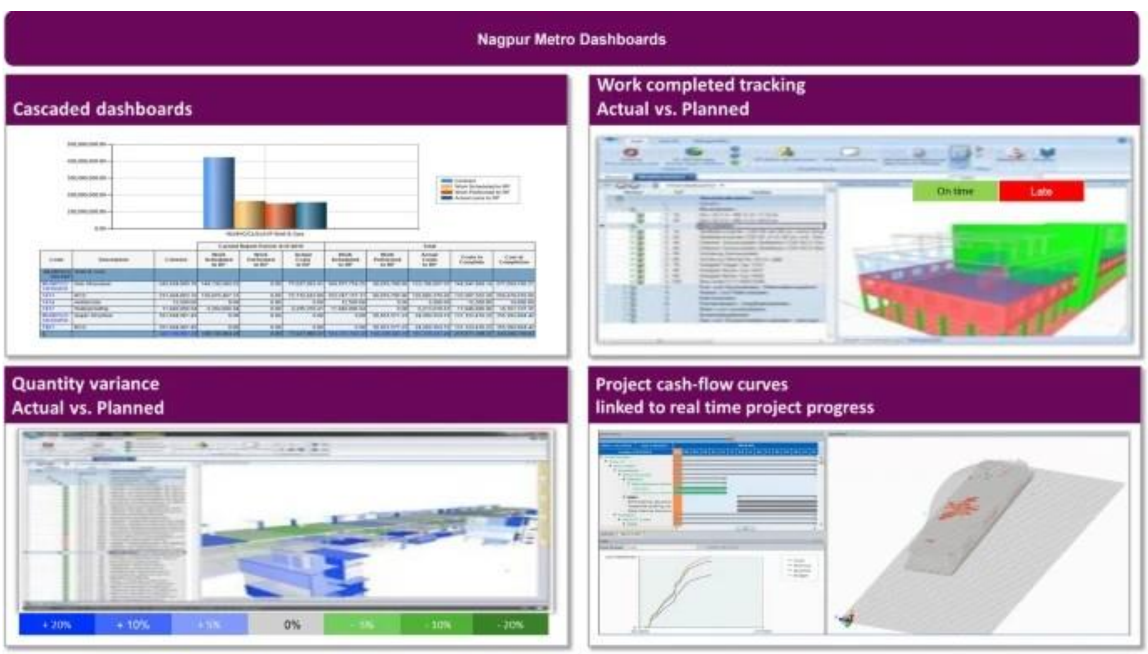


Figure 10: Nagpur Metro dashboards



Cost Optimization (Application of BIM)

The process of estimating the costs associated with a construction project using a Building Information Model (BIM) is referred to as 5D cost estimation. BIM is a digital representation of a building's physical and functional characteristics, including geometry, materials, quantities, and other relevant data.

- Niti Aayog estimates BIM may help save up to 20% on construction costs; seeks wider adoption. According to the latest report by the Ministry of Statistics and Programme Implementation, at least 355 projects have seen a cost overrun of Rs 3.88 lakh crore and about 552 projects have faced time escalation.

Estimators used to manually take off quantities from paper or CAD drawings and calculate costs based on those measurements. This process, however, is time-consuming and prone to errors. Estimators can extract the necessary information directly from the model with the use of BIM, ensuring consistency and accuracy throughout the estimating process.

Estimators can automate the quantification process by integrating BIM with cost estimating software. Estimators can spend less time counting and measuring and more time on more valuable tasks like identifying construction assemblies, factoring risks, and considering project-specific factors. This enables higher-quality estimates and the incorporation of specialised knowledge that only professional estimators have.

The use of BIM for cost estimation provides several benefits, including:

1. Early-stage cost estimation: BIM allows for early-stage design analysis and simulations, which can aid in identifying cost-saving opportunities. Potential conflicts and costly changes can be addressed before construction begins by conducting energy analysis, daylighting studies, and clash detection during the design phase.

2. Quantity takeoff and cost estimation: BIM models can be used for automated quantity takeoff, which involves extracting detailed material quantities and measurements from the digital model. Accurate cost estimations can be generated by integrating quantity takeoff data with cost databases, assisting in budgeting and cost control.

3. BIM enables value engineering, which entails reviewing and optimising the project design to achieve the best value for the available budget. Value engineering aids in the identification of cost-saving opportunities by analysing alternative design options and their associated costs.

4. Clash detection and coordination: BIM allows for the detection and coordination of clashes between various building systems and trades. Rework, delays, and additional costs during construction can be reduced by identifying clashes and interferences early on.

Figure 11: Case Study

5. Schedule optimization: BIM can be used to create a 4D construction schedule by integrating the time dimension with the 3D model. Delays can be minimised by analysing the construction sequence and identifying potential scheduling conflicts, lowering the costs associated with schedule overruns.

6. BIM models can be used for lifecycle cost analysis, which takes into account not only construction costs but also long-term operational and maintenance costs. Decisions that optimise costs throughout the building's lifespan can be made by evaluating various building systems, materials, and maintenance strategies.

7. Collaboration and communication: BIM allows for improved collaboration and communication between project stakeholders. Errors, omissions, and misunderstandings can be reduced by integrating various disciplines and streamlining information exchange, resulting in cost savings and improved project outcome

Figure 12: Design Phase

BIM saves time and money in the design phase

Area	Description	Example
Conceptual design	Quickly iterate on design elements including building form, sustainability, client requests, municipal regulations, budget, and more. Conduct analyses and simulation	The Beck Group created 100 visualizations for a church in Seoul and adjusted the shape of the building to appear curved, but with flat glass, saving over $1 million on glazing and mullions, and 1,000 hours of design time
Sustainable building design	Complete energy analysis early in the design stage to reduce ongoing energy consumption	Using BIM to evaluate design scenarios for energy savings, NASA's 50,000' building in Silicon Valley yielded features such as a steel-frame exoskeleton, geothermal wells, natural ventilation, wastewater treatment, and a photovoltaic roof that will provide 30% of the building's power
Design Documentation	Create a building model and complete set of designs documents in an integrated database, where everything is interconnected and there is real-time self-coordination of information	

Figure 13: Construction Phase

BIM saves time and money in the construction phase

Area	Description	Example
General construction	▪ Links project planning to construction planning and simulation, as well as visualization during construction and digital fabrication ▪ Enhances project communication and collaboration among teams ▪ Create more accurate cost estimates ▪ Deliver more projects on time and within budget	Contractor Robins and Morton used BIM to design and construct an Augusta, Maine hospital. Due to greater collaboration, the project was completed ten months ahead of schedule and returned approximately US$20 million in value-added savings.
Pre-fabrication, modular construction	▪ Extract information from BIM to pre-fabricate building components to improve project schedule, reduce cost, improve site safety, and produce greener construction practices by reducing material waste	J.C. Cannistraro used BIM and pre-fabrication to upgrade the central utility plant for University of Massachusetts's Boston campus helping to minimize installation time of a new HVAC system and hangers

Figure 14 : Management Phase

BIM saves time and money in the management phase

Area	Description	Examples
Lifecycle costs 	▪ Reuse building models and data to better manage facility operations ▪ Analyze data-rich models to optimize resources and reduce waste and lower lifetime maintenance and operation costs ▪ Use intelligent 3D models to help manage space and perform spatial validation for tenant chargebacks	▪ Shanghai Tower Construction & Development Co. Ltd. used BIM not only to design and build, but also to inform operations of their super high-rise tower. STC&D plans to use BIM for emergency and property management going forward. ▪ The Government Services Administration (GSA) is creating a database of its 3D models to inform O&M and future projects. Additional software leveraging the 3D models will use its data for security, updates, analysis, and reporting.

Application of BIM in mitigating environmental impact

Building Information Modelling (BIM) is a powerful tool that can be used to reduce environmental impact throughout the building lifecycle. Architects and engineers can optimise building designs for energy efficiency by using BIM, which incorporates strategies such as optimal orientation, daylighting, insulation, and HVAC systems.

BIM also makes it easier to choose and manage environmentally friendly materials, reducing embodied energy and encouraging recycling. BIM also helps with water management by facilitating efficient plumbing layouts, rainwater harvesting, and stormwater management systems.

The incorporation of life cycle assessment (LCA) tools into BIM allows for a thorough evaluation of a building's environmental impacts, guiding design decisions for reduced resource consumption and emissions.

Energy Analysis

BIM allows for energy analysis and simulation, which helps designers evaluate the energy performance of a building and identify areas for improvement. By analysing factors like heating, cooling, lighting, and insulation, BIM can optimise energy efficiency and reduce carbon emissions.

Figure 15: Energy Model

Revit enables designers to create and modify building geometry, assign thermal properties, and model HVAC and lighting systems, facilitating accurate energy analysis. With energy analysis tools and simulations, Revit optimizes energy performance, evaluates efficiency, and identifies areas for improvement. It generates comprehensive reports summarizing energy consumption, carbon emissions, and potential energy-saving measures. Performing system analysis in Revit involves creating a detailed model, defining parameters, simulating energy consumption and HVAC performance, optimizing lighting design, and analyzing results for informed decision-making.

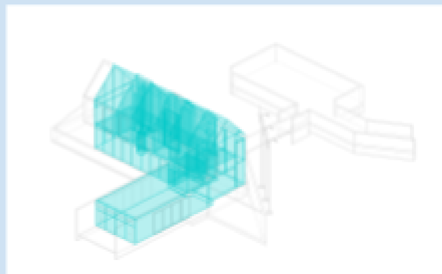


Figure 16: Sun View Analysis

Revit is a popular BIM software that provides energy analysis capabilities to evaluate a building's energy performance.

The sun view analysis features in Revit assist designers in understanding the building's interaction with sunlight, optimising daylighting, managing solar heat gain, and improving energy performance. Architects can create more sustainable and comfortable buildings by considering the sun's path and its effects, while reducing the need for artificial lighting and excessive energy consumption.

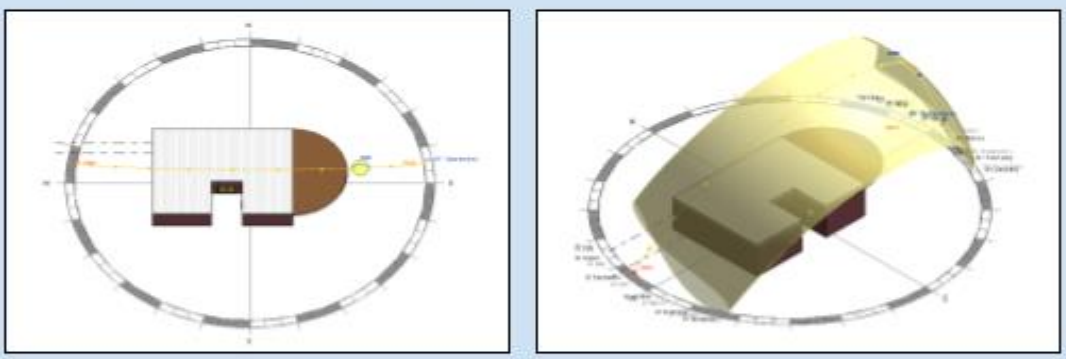


Figure: Revit Software can generate sun path diagrams, which provide a visual representation of the sun's movement throughout the year. These diagrams show the sun's azimuth and altitude angles at different times of the day and year

Global climate change

To overcome this global climate change (GCC), global warming Potential (GWP) caused by CO2 emission. Estimation of The Carbon Footprint Of Construction Materials Used In Civil Engineering construction.

The estimation method is based on strong correlations observed between the established city baselines and three climate characteristics that influence a building's energy demands and resulting operational carbon footprint. High wet bulb temperatures, high dry bulb temperatures, and low dry bulb temperatures are the three characteristics used. These have an impact on latent cooling, sensible cooling, and heating energy demands. We can estimate baselines for new locations based on only the local weather characteristics and the underlying carbon intensity of the local fuel supply by determining the correlation between existing city baselines and each of these characteristics.

Box-1

Weather conditions and their impact on various aspects of life are greatly influenced by wet bulb temperature, dry bulb temperature, and their variations. Let's take a look at each of these ideas separately.

1. Wet Bulb Temperature: The wet bulb temperature is the lowest temperature attained by evaporating water into the air at constant pressure. It gives information about the cooling potential of evaporative processes and is influenced by both the dry bulb temperature (normal temperature) and the moisture content of the air.

   High Wet Bulb Temperature: High wet bulb temperatures indicate that the air is already saturated with moisture and that the evaporation process is less effective in cooling the surrounding environment. This condition frequently causes discomfort as well as an increased risk of heat-related illnesses. Extremely high wet bulb temperatures above a certain threshold (usually around 35°C or 95°F) can be life-threatening and have serious consequences for human health, especially in humid areas.

2. Dry Bulb Temperature: The dry bulb temperature refers to the ambient temperature measured by a regular thermometer. It represents the temperature of the air without factoring in the moisture content.

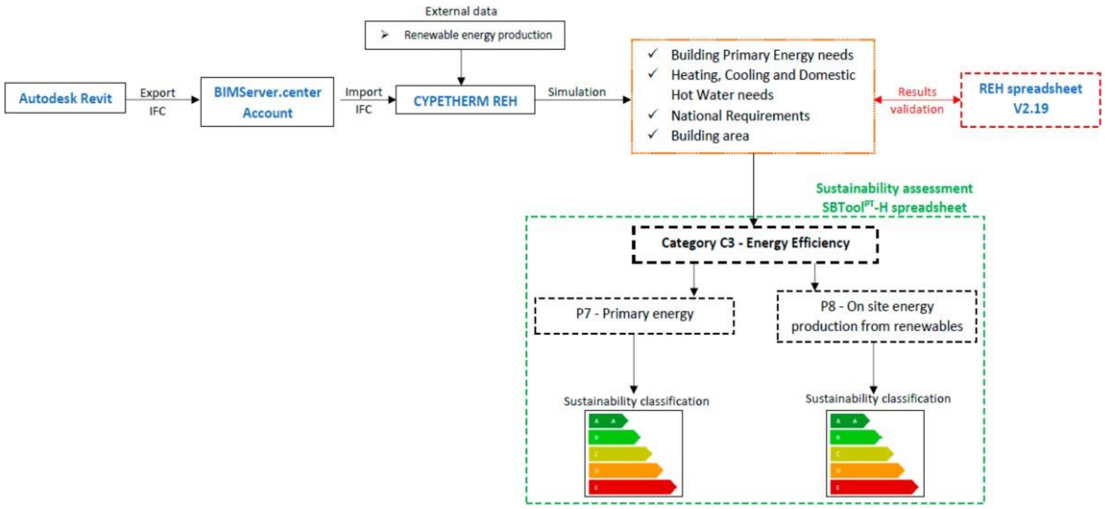
   High Dry Bulb Temperature: Hot weather conditions are indicated by high dry bulb temperatures. These temperatures can vary depending on location and climate, but they typically cause increased heat stress and can pose health risks, particularly when combined with high humidity. Summer heatwaves are frequently associated with high dry bulb temperatures, which can cause heat exhaustion, heatstroke, and dehydration.

   Low Dry Bulb Temperature: Low dry bulb temperatures suggest cold weather conditions. The severity of cold temperatures depends on the region and its typical climate. Extremely low dry bulb temperatures can result in frostbite, hypothermia, and other cold-related health issues. It's important to take appropriate measures to stay warm and protect yourself in such conditions.

Why established on a city-by-city basis?

Local climate, such as daily and seasonal temperature and weather patterns which affect demand for lighting, heating and cooling etc.

Figure 17: Sustainable Energy Is Used



Key Point

- Carbon equivalent
- Developing an automated BIM-based life cycle assessment approach for modularly designed high-rise buildings

Carbon Equivalent

To calculate the carbon equivalent in a carbon footprint, take into account the emissions of various greenhouse gases and convert them into a common unit of measurement, usually carbon dioxide equivalent (CO_2e).

Steps to Calculate CO_2e:

1. Identify the greenhouse gases
2. Global warming potential (GWP): used to assess the warming potential of various greenhouse gases in comparison to carbon dioxide (CO2). It measures a greenhouse gas's ability to trap heat in the atmosphere over a specific time horizon, typically 20 years, 100 years, or 500 years.
   The Global Warming Potential (GWP) values are based on scientific assessments by organisations such as the Intergovernmental Panel on Climate Change (IPCC). The GWP values are calculated by comparing the radiative forcing (energy trapped in the Earth's atmosphere) caused by a given mass of a greenhouse gas to the same mass of carbon dioxide over a given time period.
3. Emission data

4. Convert emissions to CO_2e
5. Sum up the CO2e values

Carbon dioxide (CO2) is used as the reference gas with a GWP of 1, as it is the most abundant and persistent greenhouse gas. Other greenhouse gases have higher GWP values, indicating they have a greater warming potential compared to CO2. For example, methane (CH4) has a GWP of 25 over a 100-year time horizon, meaning it has 25 times the warming potential of CO2 over that time period.

$$CO_2e = Emissions\ of\ a\ greenhouse\ gas\ (in\ metric\ tons) \times GWP\ of\ that\ gas$$

Automated BIM-based life cycle assessment approach for modularly designed high-rise buildings

The developed approach can support automated assessments throughout all phases of a prefabricated buildings lifecycle. It is accomplished through an automated process that includes systematic zoning, model setup, and impact estimation.

By addressing specific prefabrication characteristics, automated BIM-based LCA is promoted, as is the incorporation of comprehensive and detailed LCA data into BIM models for improved design robustness and holistic building performance. This validated approach will increase designers' willingness to use LCA during the design stages to reduce the energy and environmental impacts of both new and renovated buildings using prefabrication.

Modular Construction : Modular construction refers to a process in which building components are constructed off-site. These components are then transported as a completed component to a building site. The modular construction institute reported that modular construction allowed projects to be completed in half the time of the conventional construction.
prefabricated buildings: Their origins can be traced back to the late European colonial period and the post-World War I period, when there were numerous temporary and emergency prefabricated edifices.The majority of these systems were used to build edifices at minimal cost in short timeframes, often at the expense of quality.

- The construction industry is a major source of environmental issues since buildings contribute 39% of the annual global carbon emissions due to the production of construction materials and direct or indirect energy use during the operation phase.

- In high-density cities like Hong Kong, buildings account for 90% of carbon emissions from electricity consumption in the operation phase.

Life Cycle assessment (LCA) is increasingly adopted to realize low carbon transition of the building industry. LCA is applied to evaluate the energy use and environmental impacts of material production, construction, operation, and end-of-life.

Prefabrication involves manufacturing building components/assemblies in a factory before transporting and installing on site. It has been proved to alleviate problems such as high construction cost, onsite waste generation, health and safety risks, and high energy use and carbon emission. In Hong Kong, the use of modular design and prefabricated construction is mainly promoted by the Housing Authority. 90s(18% adapted) 2008 (35% adapted) by 2013 roof,partition wall,garden floor is possible 2016 (65% adapted).

BIM is a digital representation of a physical facility which serves as a repository for multidisciplinary data. It also has inherent capabilities to manipulate and generate data required for a wide range of building assessments. Particularly for prefabricated buildings, identifies potential for the seamless dissemination and data exchange within a BIM and prefabrication system which can improve the project cost, time and resource performance. BIM can reduce the overall project duration through parallel executions of trades. Integrated BIM-based LCA for the whole lifecycle design, prefabrication, transportation, installation, and end-of-life cycle phase (Unexplored). Integrated BIM-based LCA of prefabricated/modular construction, a real-time evaluation and improvement can be performed to reduce different life cycle impacts of buildings. BIM-based LCA can mitigate challenges of conventional LCA process, which is time-consuming, costly and involves manual data entry.

1. BIM makes BOQ(Bill of Quantity) easy.
2. workflows combining BIM.
3. The inclusion and manipulation of LCA data within the BIM environment is a more effective approach to harness the power of BIM such as real time LCA during design changes.

Existing studies did not consider various levels of prefabrication, they cannot provide systematic insights into the lifecycle performance of prefabricated buildings. Material production phase is usually the main focus whereas other lifecycle phases remain fairly unexplored. Existing studies on integrated BIM-based LCA in buildings have mainly focused on early design stages, evaluating material use and environmental performance. Expanded this research to the entire design phase, exploring different BIM models and evaluating environmental performance.

Opportunities to reduce embodied impacts through transportation and end-of-life strategies. Prefabricated buildings' construction methods differ significantly from conventional buildings, making it necessary to develop a BIM-based approach suitable for different phases.

Categorising buildings based on their construction and insulation characteristics

1. Heavy Building: Heavy buildings are typically constructed with substantial materials such as reinforced concrete, steel, or masonry. These materials provide high load-bearing capacity, allowing the building to support larger loads, multiple stories, and heavier equipment or machinery.
2. Light Building: Light buildings, on the other hand, are constructed with lighter materials such as wood, light steel framing, or lightweight concrete. They have a lower load-bearing capacity and are suitable for smaller structures and fewer stories.
3. Poorly Insulated Heavy Building: A building with inadequate insulation and significant thermal mass, such as concrete or brick walls. It experiences high heat loss/gain and requires substantial energy for heating and cooling.
4. Highly Insulated Heavy Building: This type features good insulation and considerable thermal mass, resulting in reduced heat loss/gain and lower energy consumption for maintaining comfortable indoor conditions.
5. Medium Insulated Heavy Building: Moderate levels of insulation and thermal mass characterise this building type, leading to moderate heat retention and energy needs for heating and cooling.
6. Poorly Insulated Light Building: A building with minimal insulation and lightweight construction materials like wood or metal. It suffers from substantial heat loss/gain and demands significant energy for temperature control.
7. Highly Insulated Light Building: This type boasts efficient insulation and lightweight materials, leading to reduced heat loss/gain and lower energy usage for heating and cooling purposes.
8. Medium Insulated Light Building: Moderate levels of insulation and lightweight construction characterise this building type, offering moderate heat retention and energy consumption for indoor climate regulation.
9. Super Insulated Heavy Building: This building features exceptionally high insulation levels and substantial thermal mass, resulting in minimal heat loss/gain and extremely low energy requirements for heating and cooling.
10. Super Insulated Light Building: A highly insulated building with lightweight construction materials, ensuring minimal heat loss/gain and very low energy consumption for maintaining comfortable indoor conditions.

Practical Application of BIM Energy Simulation

Location : Jodhpur

1. Climate File

Time Period : 1981-2010

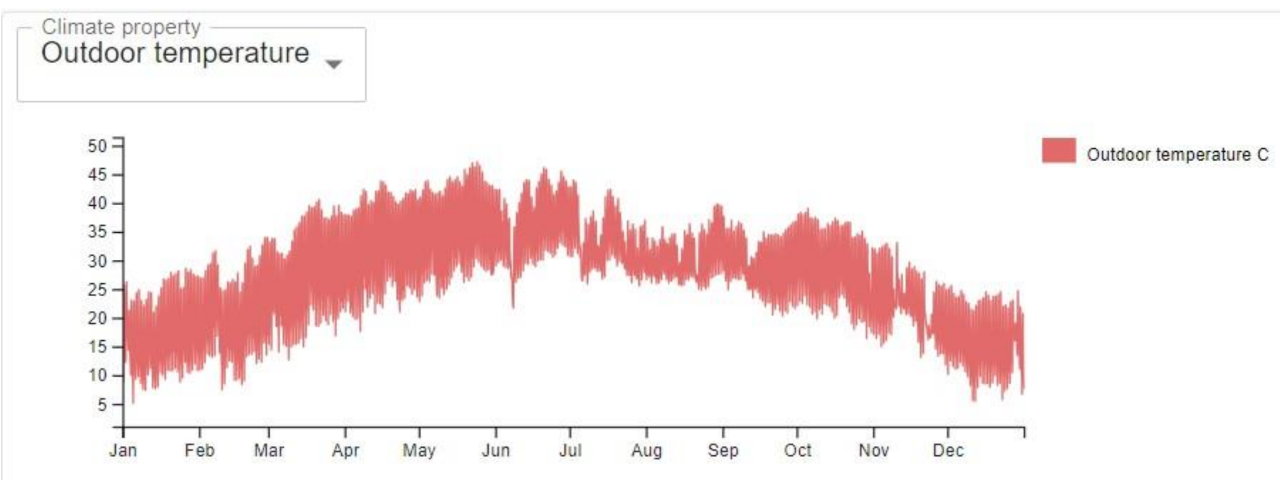


Figure 18 : Outdoor Temperature

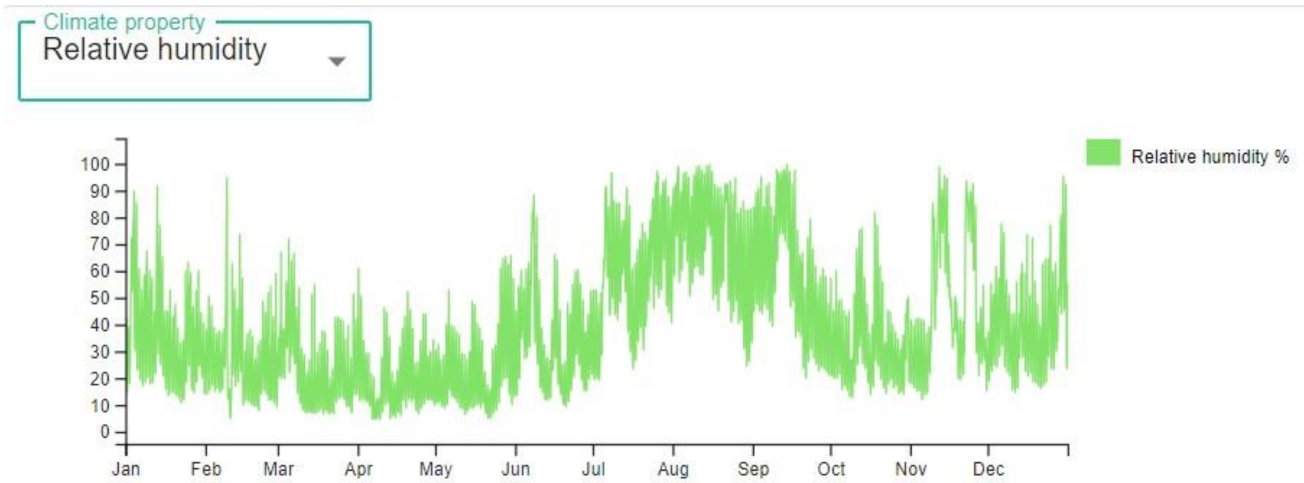


Figure 19 : Relative Humidity

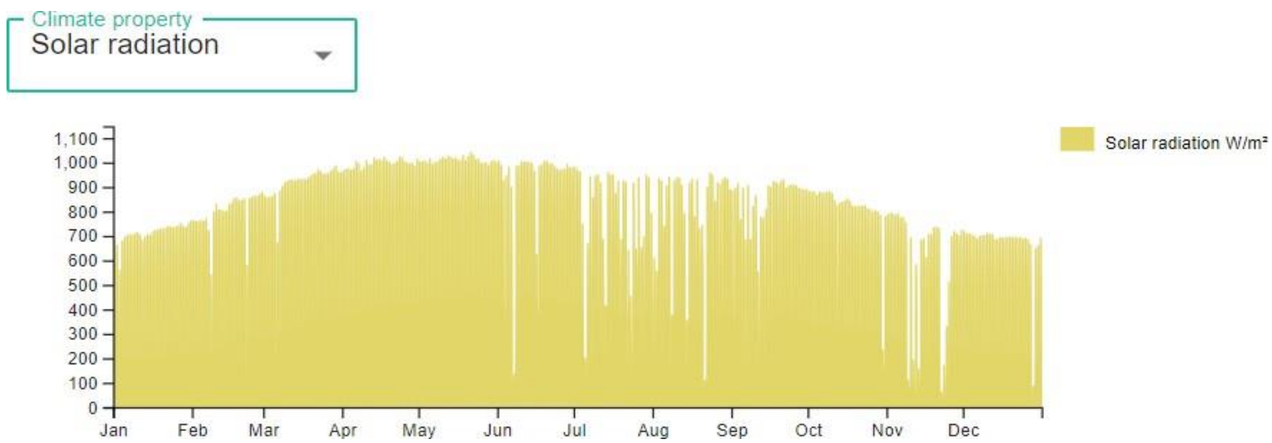


Figure 20 : Solar Radiation

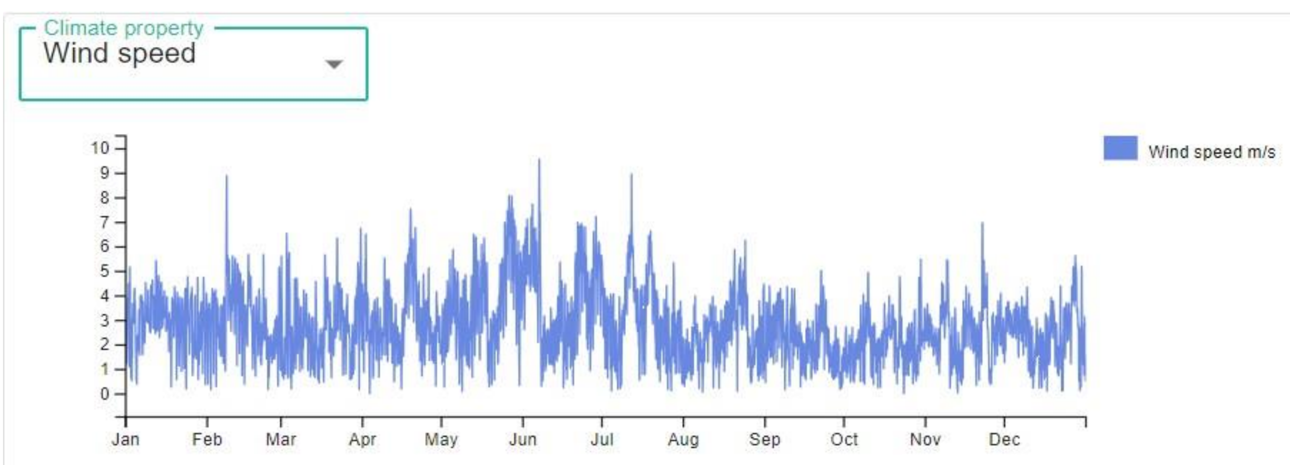


Figure 21 : Wind Speed

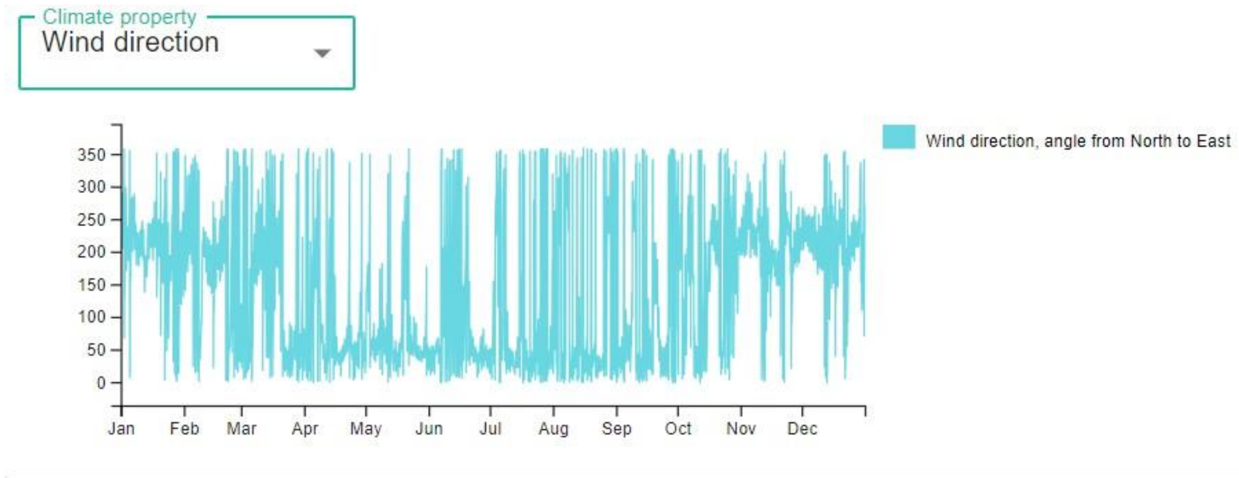
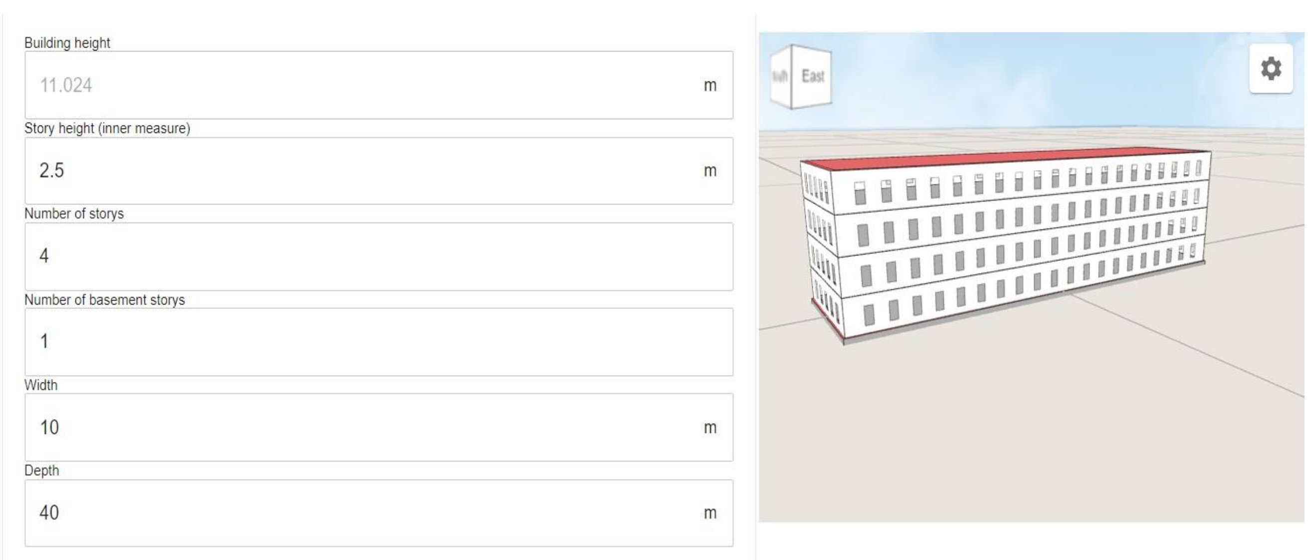


Figure 22 : Wind Direction

2. Building

- Heated Floor Area : The total area of a building or a specific space within the building that is actively heated during cold weather to maintain a comfortable indoor temperature. This area includes all the rooms and spaces that are heated, such as living rooms, bedrooms, kitchens, etc.



- Thermal bridges, also known as cold bridges or heat bridges, refer to areas in a building's envelope (walls, roof, floor, or windows) where there is a higher rate of heat transfer than in the surrounding materials. These regions act as pathways for heat to flow more easily from the interior to the exterior or vice versa, leading to localised heat loss or gain and potentially creating areas of discomfort or condensation.

Thermal bridge	Psi Value	Amount	Length
External wall / External wall	0.20	28	75.7
External wall / Internal slab	0.20	28	480.0
Windows and doors	0.04	240	1018.2
Underground wall / Underground slab	0.27	7	120.0
Underground wall / Underground wall	0.20	7	17.5
External wall / Roof	0.14	7	120.0

Name	Orientation	Type	Lowest Level (m)	Highest Level (m)	Amount	Area (m^2)
Basement floor	BF 0-6M	Underground slab	-2.5	-2.5	1	500.0
Poorly insulated heavy building, interior floor	INNER	Interior floor	0.0	8.5	8	4000.0
Basement wall	BW 0-1M	Underground wall	-1.0	0.0	7	120.0
Basement wall	BW 1-2M	Underground wall	-2.0	-1.0	7	120.0
Basement wall	BW >2M	Underground wall	-2.5	-2.0	7	60.0
Poorly insulated heavy building, exterior wall	WEST	Exterior wall	0.3	11.0	4	320.0
Poorly insulated heavy building, exterior wall	SOUTH	Exterior wall	0.3	11.0	8	160.0
Poorly insulated heavy building, exterior wall	EAST	Exterior wall	0.3	11.0	8	320.0
Poorly insulated heavy building, exterior wall	NORTH	Exterior wall	0.3	11.0	8	160.0
Poorly insulated heavy building, roof	ROOF	Roof	11.0	11.0	1	500.0
Poorly insulated heavy building, double glazed window	WEST	Window	0.5	10.2	80	80.0
Poorly insulated heavy building, double glazed window	SOUTH	Window	0.5	10.2	40	40.0
Poorly insulated heavy building, double glazed window	EAST	Window	0.5	10.2	80	80.0

Before Energy Simulation

Average U-value:
1.03 W/m²,K

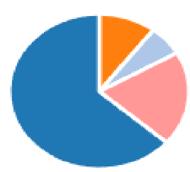
Average ventilation flow :
0 l/s,m²

Total energy use:
56697 kWh/year

Energy performance:
22.7 kWh/m²/year

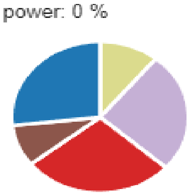
Emitted energy

- Transmission: -13.2 %
- Infiltration: 8.2 %
- Ventilation: 0 %
- Waste water: 24.7 %
- Cooling: 80.3 %

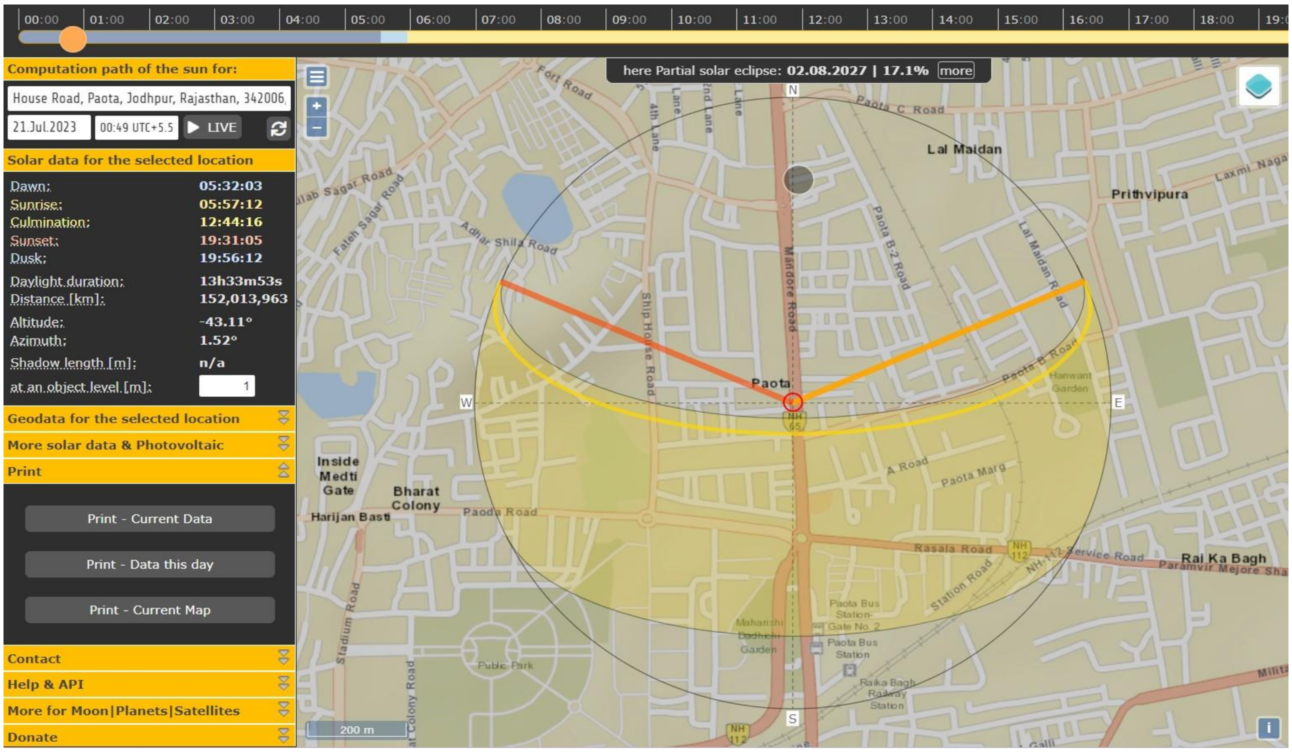


Supplied energy

- Energy recovery ventilation: 0 %
- Heat recovery tap water: 0 %
- Energy recovery heat pump: 0 %
- Solar energy through windows: 10.8 %
- Process energy room: 25.8 %
- Heat supply: 27.9 %
- Electricity use: 0 %
- Human heat gain: 8.6 %
- Latent energy: 26.9 %
- Photovoltaic power: 0 %

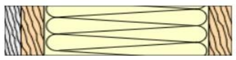
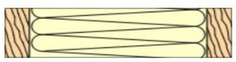
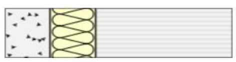


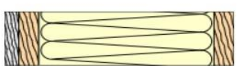
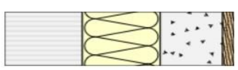
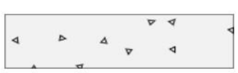
- Azimuth angle is a measure of the sun's position relative to an observer's location and is influenced by the local topography, including surrounding buildings, hills, and other structures.



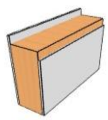
- A high azimuth angle is generally desirable for solar energy applications, as it allows for more direct sunlight and greater solar energy capture by solar panels or solar collectors. In contrast, a low azimuth angle, such as during sunrise or sunset, means the sun is closer to the horizon, and the solar energy received is less intense.
- Wind Velocity % climate file : Freely exposed buildings 95%, Moderately protected buildings 70%, Inner city buildings 45%
- Albedo (Solar reflection from ground)(percentage)

3. Construction

Constructions set for Poorly insulated heavy building				
Type	Display	Name	Thickness (m)	U-value (W/m²,K)
Exterior wall:		Poorly insulated heavy building, exterior wall	0.34	1.41
Roof:		Poorly insulated heavy building, roof	0.28	0.61
Slab on grade:		Poorly insulated heavy building, slab on grade	0.30	1.56
Interior wall:		Poorly insulated heavy building, interior wall	0.16	2.44
Interior floor:		Poorly insulated heavy building, interior floor	0.26	0.71
Underground wall:		Basement wall	0.50	0.25

Constructions set for Highly insulated heavy building				
Type	Display	Name	Thickness (m)	U-value (W/m²,K)
Exterior wall:		Highly insulated heavy building, exterior wall	0.40	0.25
Roof:		Highly insulated heavy building, roof	0.32	0.16
Slab on grade:		Highly insulated heavy building, slab on grade	0.44	0.21
Interior wall:		Highly insulated heavy building, interior wall	0.07	4.74
Interior floor:		Highly insulated heavy building, interior floor	0.16	3.79

Poorly insulated heavy building, exterior wall U-value 1.41 W/m²K



☑ Show 3D

Properties	Value	Unit
U-value:	1.41	W/m²K
Delta U:	0	W/m²K
Solar Absorption:	50	%
Air leakage q50:	0.5	l/s, m²

Material layers from the outside

Lime and cement mortar	0.02 m
Facade brick	0.3 m
Lime and cement mortar	0.02 m

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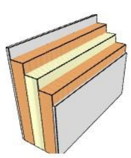
Highly insulated heavy building, exterior wall U-value 0.25 W/m²K



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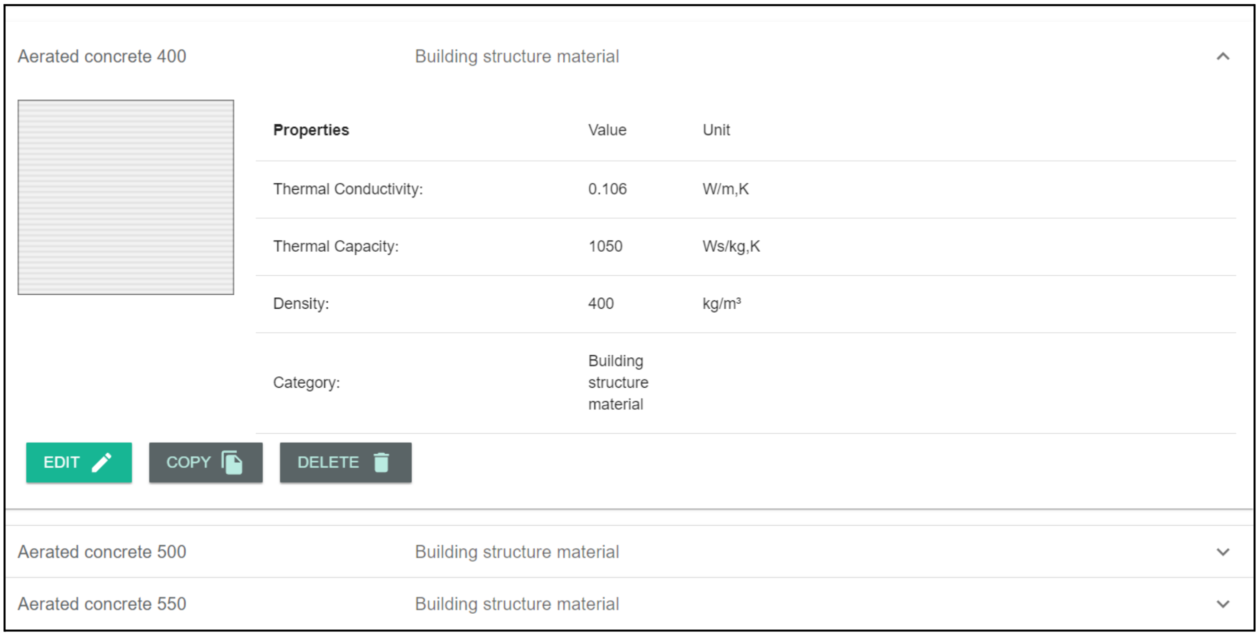
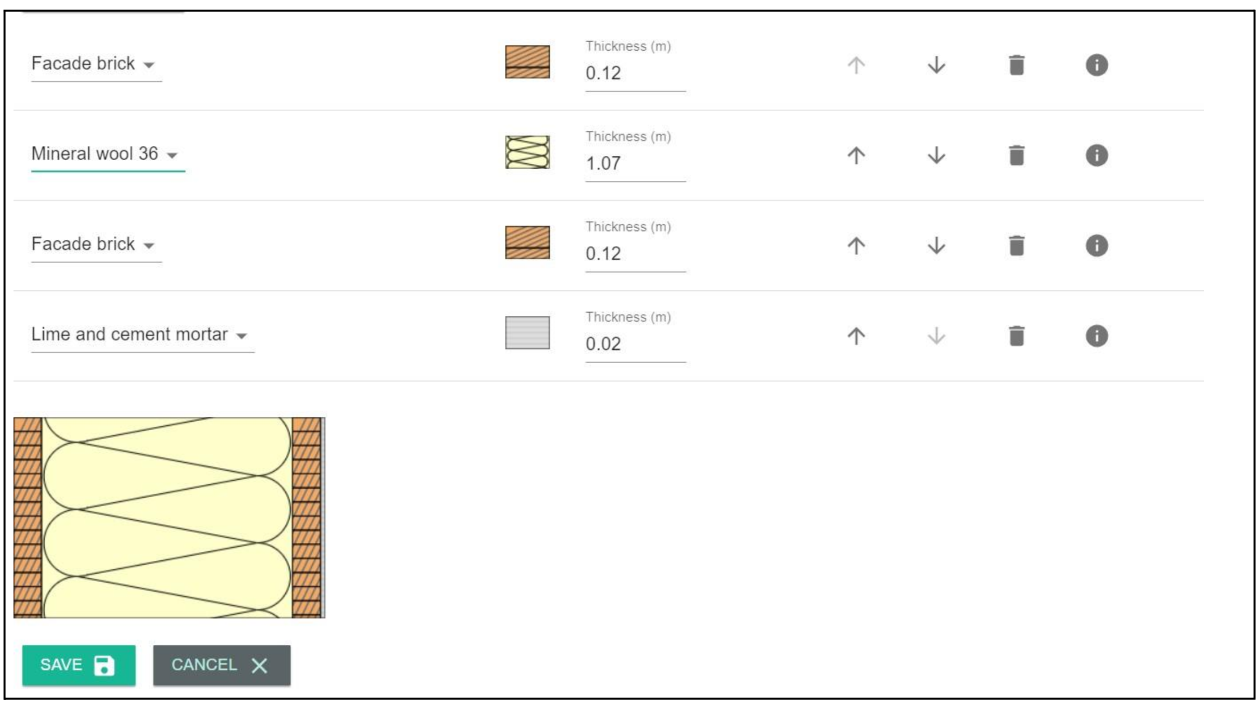
Properties	Value	Unit
U-value:	0.25	W/m²K
Delta U:	0	W/m²K
Solar Absorption:	50	%
Air leakage q50:	0.5	l/s, m²

Material layers from the outside

Lime and cement mortar	0.02 m
Facade brick	0.12 m
Mineral wool 36	0.12 m
Facade brick	0.12 m
Lime and cement mortar	0.02 m

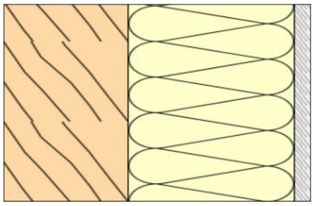
The U-value (also known as thermal transmittance or thermal conductivity) of a material refers to its ability to conduct heat. A lower U-value indicates that the material has better insulating properties, as it restricts heat transfer more effectively. Conversely, a higher U-value indicates that the material allows heat to pass through more easily, making it less thermally efficient.





Make Own Material

Outer Wall 1 U-value 0.33 W/m²K



Show 3D

Properties	Value	Unit
U-value:	0.33	W/m²K
Delta U:	0	W/m²K
Solar Absorption:	50	%
Air leakage q50:	0.5	l/s, m²

Material layers from the outside

Wood	0.075 m
100 mm mineral wool 36 between wooden studs 45mm, cc600	0.1 m
Plywood	0.01 m

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"Change Comes After One Material Change: Transforming the Exterior Wall"

Indicators

Average U-value:
0.63 W/m²,K

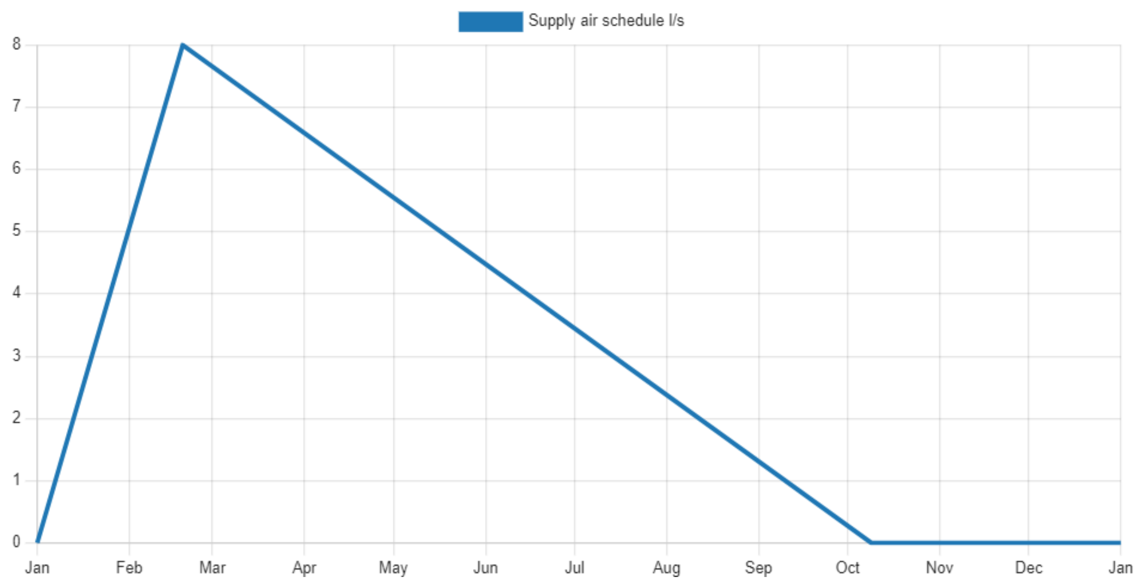
Average ventilation flow :
0 l/s,m²

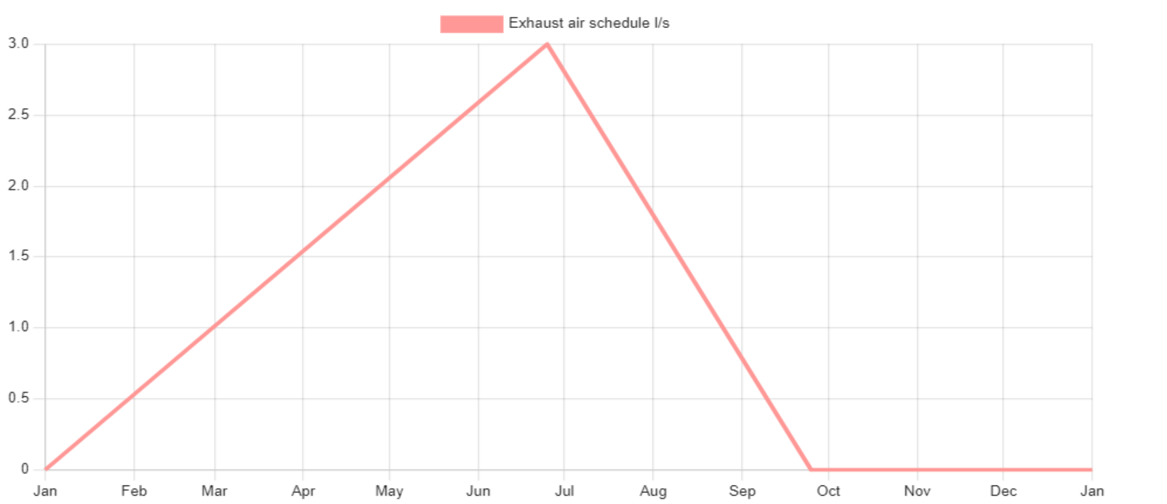
Total energy use:
50751 kWh/year

Energy performance:
20.3 kWh/m²/year

4. Ventilation

process of providing fresh air to indoor spaces to maintain a healthy and comfortable environment for occupants. The primary goals of ventilation are to remove indoor pollutants, control moisture levels, and ensure an adequate supply of oxygen for occupants.





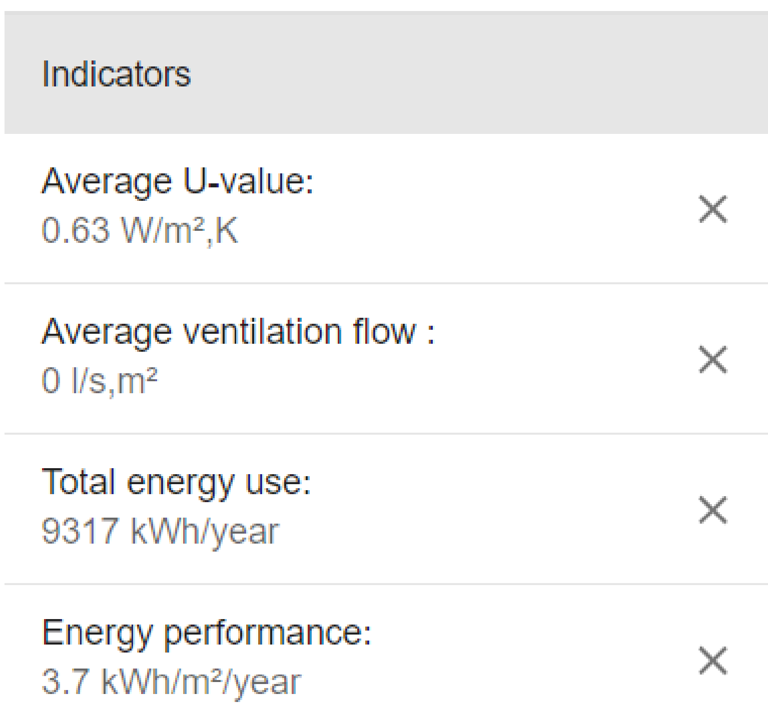
5. Heating:

   Water-borne heating, also known as hydronic heating or radiant heating, is a method of space heating that uses hot water as the heat transfer medium. In this system, hot water is circulated through pipes or tubes installed in the floors, walls, or ceilings of a building to provide even and efficient heating. The heat is then radiated from the surfaces to warm the surrounding spaces and occupants.

   Comparison of Water-Borne Heating (Hydronic) and Electric Heating:

   Efficiency: Water-borne heating is generally more energy-efficient than electric heating, as water has a higher heat capacity and can store and distribute heat more effectively. Comfort: Water-borne heating provides more even and comfortable heating through radiant heat transfer, while electric heating may lead to localised temperature variations and a less uniform heating experience.

   Installation Cost: Hydronic systems can have higher upfront installation costs due to the need for piping and boiler equipment, while electric heating systems typically have lower initial costs and are easier to install. However, the long-term energy savings of water-borne heating can offset the higher initial investment.



The geothermal rock plays a crucial role in the efficiency of the geothermal heat pump system. Because the Earth's thermal mass remains relatively stable throughout the year, the geothermal rock provides a relatively constant and moderate temperature source or sink, depending on the season.

6. Cooling:

Passive cooling refers to the design and construction of buildings to maintain comfortable indoor temperatures without relying heavily on mechanical cooling systems

- Shading and Insulation: Using shading devices, such as overhangs and louvres, to block direct sunlight and employing high-quality insulation to reduce heat transfer.
- Orientation and Building Shape: Optimising the building's orientation and shape to maximise natural ventilation and minimise solar heat gain.
- Natural Ventilation: Designing the building with operable windows, vents, and stack effect to promote natural airflow and ventilation.
- Thermal Mass: Incorporating materials with high thermal mass (e.g., concrete, stone) to absorb and store heat, moderating indoor temperature fluctuations.
- Night Cooling: Allowing cool nighttime air to naturally cool the building, often through strategic window openings or ventilation systems.

District cooling is a centralised cooling system that serves multiple buildings or a whole district from a central plant. In this system, chilled water is produced at the central plant and then distributed through a network of underground pipes to individual buildings. The chilled water is used to cool down air in buildings' air conditioning systems, providing a more efficient and sustainable cooling solution compared to individual cooling systems for each building. District cooling is an energy-efficient approach as it allows for the use of larger and more efficient cooling plants, waste heat recovery, and optimised operation

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