

# Application Of BIM For Life-Cycle Cost Analysis Of Bridge: Case Study

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## ABSTRACT

*BIM has been successfully adopted in the building construction industry worldwide. However, its potential for infrastructure remains largely underutilized due to several factors. In transportation infrastructure management, BIM can provide further benefits by integrating multiple elements such as scope, schedule, budget, maintenance records, project specifications, warranty information, purchase orders, existing service documentation, and MEP models into a 3D model. The present study involves work on use of BIM for performing life-cycle cost analysis of bridge which demonstrates the use of BIM for an infrastructure project. The use of BIM in different stages of design varies as per the requirement and due to this reason, it becomes mandatory to implement BIM suitably. The work consists of modelling of a bridge constructed in Pune district in the state of Maharashtra to perform life-cycle cost analysis. It involves developing 3D, 4D and 5D models of the designated bridge and then further estimate the entire cost including the maintenance and repair cost using life-cycle cost analysis method throughout its life span. Conceptual 3D, 4D and 5D models developed gives clear idea regarding scope, schedule and estimated cost for construction of the bridge. Further, life-cycle cost analysis gives a more detailed estimation of cost which includes maintenance and repair cost of the infrastructural project. It can be observed that this analysis can help the personnel involved in designing, planning, scheduling and execution to work more efficiently and cost effectively giving a broader idea about the financial aspect of the bridge to all its stakeholders.*

**Keywords:** *Life-Cycle Cost Analysis; BIM for Infrastructure; Conceptual Model; 3D, 4D and 5D Modelling; Bridge*

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## INTRODUCTION

Bridges are essential to contemporary infrastructure by enhancing connectivity, fostering economic growth, and facilitating social integration. However, their sustainable existence is progressively threatened by deteriorating structural materials, escalating maintenance costs, and antiquated lifecycle management practices. Conventional approaches to Life Cycle Cost Analysis (LCCA) that aim to calculate the overall costs of infrastructure from construction through disposal frequently face limitations due to scattered data and rigid planning frameworks. These limitations impede the consideration of essential factors like material fatigue, environmental influences, and upcoming maintenance requirements. As the focus on sustainability and budget effectiveness increases, governments and infrastructure stakeholders need sophisticated tools that facilitate informed, strategic decision-making over the long term. Building Information Modeling (BIM), a digital tool for creating data-rich intelligent 3D models, has greatly changed processes in the architecture, engineering, and construction industries. Although the advantages of BIM are well recognized in building projects, its use in bridge infrastructure, especially in relation to LCCA, is still developing. Because of their intricate geometry, diverse structural components (such as girders, bearings, and substructures), and long operational lifespan, bridges require specialized BIM procedures. Integrating maintenance schedules, cost metrics, and environmental information into a consolidated BIM platform enables stakeholders to transition from reactive responses to proactive, predictive management. This shift results in enhanced operational effectiveness and sustainable financial strategy.

LCCA is a crucial instrument that evaluates the complete economic implications of a building throughout its entire lifespan, not just during initial construction expenses. It takes into account ongoing costs like regular maintenance, repair work, energy consumption, and sustainability results. This all-encompassing method is particularly beneficial for structures such as bridges, where immediate cost savings may lead to significant long-term financial liabilities. LCCA allows for the assessment of alternatives such as various design approaches or material options by employing methods like Net Present Value (NPV) and

Equivalent Annual Cost (EAC), facilitating improved resource distribution over time. Nevertheless, conventional LCCA methods frequently struggle to handle the intricacies of actual projects. They usually entail hands-on data gathering, depend on fixed economic premises, and function within isolated software platforms, resulting in inaccuracies in cost estimation. These constraints are emphasized in infrastructure systems such as bridges, where separate components deteriorate at different speeds and need diverse maintenance approaches. Combining BIM with LCCA addresses these obstacles by providing real-time data visualization, performance condition simulations, and automated financial analysis. This integration improves the precision and practicality of lifecycle planning.

This study seeks to improve the efficiency of LCCA in bridge asset management through the use of BIM technologies. This integration tackles essential infrastructure issues, such as proactive identification of maintenance requirements, diminished risks, and enhanced sustainability monitoring. This framework ultimately fosters more prudent financial choices while aiding global sustainability efforts, like the United Nations Sustainable Development Goals (SDGs), by reducing resource waste and extending the lifespan of infrastructure

## BACKGROUND

Bridges serve a crucial function in worldwide infrastructure systems, acting as key connections within transport networks that facilitate economic activity, social engagement, and emergency logistics. Nonetheless, the increasing challenges of aging infrastructure, evolving climate conditions, and budget limitations have exposed deficiencies in traditional bridge management methods. Historically, maintenance strategies have been reactive, with repairs conducted only once noticeable damage is observed. While easy to execute, this approach frequently leads to increased overall expenses because of unforeseen failures, prolonged service interruptions, and premature structural replacements. To tackle these inefficiencies, Life Cycle Cost Analysis (LCCA) has arisen as a forward-thinking approach, allowing stakeholders to evaluate the overall costs connected to a bridge from its initial planning to final disposal. This approach enables decision-makers to evaluate not just direct construction expenses but also aspects such as material deterioration, energy use, and ecological effects, resulting in more economically viable and sustainable outcomes. Nevertheless, in spite of its benefits, traditional LCCA methods face numerous drawbacks. This encompasses reliance on manual data input, inflexible assumptions about upcoming pricing and maintenance requirements, and inadequate collaboration among project stakeholders. These problems are especially important in bridge infrastructure, where the reliance on components like piers, bearings, and decks increases complexity.

The emergence of Building Information Modeling (BIM) has created fresh opportunities to tackle these difficulties. Originally created for vertical building projects, BIM's extensive 3D modeling and data integration features are now being modified for civil infrastructure uses. In bridge projects, BIM aids in developing digital representations or "digital twins" that represent the bridge's physical and functional features. These models can replicate actual conditions, like traffic stress or environmental loads, and archive essential information such as material specifications, repair history, and lifecycle expenses. Even with its possibilities, the application of BIM alongside LCCA is still relatively unadvanced in the realm of bridges. Although the use of BIM in the construction industry is common, bridge structures pose specific difficulties owing to their intricate shapes, fluctuating load conditions, interaction with the ground, and prolonged service lives. A significant portion of the existing literature presents either theoretical frameworks or restricted case studies, failing to provide practical and reproducible workflows that can be applied more widely.

BIM greatly enhances infrastructure progress by consolidating project information and promoting cooperation among all parties involved. In the planning phase, it combines spatial, environmental, and utility information into a cohesive 3D framework that enhances site selection and facilitates early risk detection. During the design phase, smart parametric elements such as abutments, beams, and columns are enhanced with information like expenses, materials, and upkeep needs. BIM enhances design coordination by identifying clashes, reducing conflicts among structural, electrical, and mechanical systems prior to the commencement of construction. As projects advance, 4D BIM connects construction

timelines with the 3D model to illustrate progress over time, while 5D BIM integrates real-time cost data to facilitate immediate budget modifications. Following construction, the BIM model turns into a useful resource for operations and maintenance, containing details like warranties, inspection logs, and predictive instruments that assist in forecasting future wear based on usage patterns.

## LITERATURE REVIEW

Building Information Modeling (BIM) has demonstrated the ability to enhance efficiency and minimize rework in intricate infrastructure projects. Fanning et al. (2014) performed a comparative case analysis on two bridge construction projects—one utilizing BIM and the other not—and discovered that the use of BIM decreased requests for information (RFIs), change orders, and project rework. Although there was a 70% rise in upfront expenses, the BIM-enabled initiative achieved a 5–9% decrease in construction costs due to enhanced planning and reduced mistakes. The research emphasizes the importance of BIM in facilitating intricate project implementation and asset management.

(Fanning, Clevenger, Ozbek, & Mahmoud, 2014; DOI: 10.1061/(ASCE)SC.1943-5576.0000239).

Value Management (VM) is a useful method aimed at improving project value by recognizing and substituting materials that generate excessive expenses. Muthuckannal and Chitra (2021) utilized VM in a flyover project by assessing traditional materials via life cycle cost analysis and functional value evaluations. Methods such as FAST diagrams, cost-benefit analysis, and analytical hierarchy process were employed to uncover cost-saving options. The research revealed that utilizing alternative materials reduced the project cost by 4% and enhanced value by as much as 98% throughout its lifetime. Their results endorse the incorporation of VM in infrastructure initiatives for enhanced cost-effectiveness and sustainability.

(Muthuckannal & Chitra, 2021; DOI: 10.35629/5252-030617201728).

Building Information Modeling (BIM) is progressively utilized in civil infrastructure to improve collaboration, asset management, and integration of lifecycle data. Though commonly utilized in construction projects, its application in bridges and roads is still evolving because of specific geometric, operational, and coordination hurdles. The research emphasizes how BIM enables effective planning, upkeep, and remodeling using technologies such as LiDAR, GIS, and IFC data interchange. Asefa's study further shows that Bridge Information Modeling (BrIM) provides enhanced inspection and decision-making resources for transportation authorities. (Asefa, 2022, The Catholic University of America). Fast urban growth and rising vehicle counts have resulted in severe traffic jams at intersections, necessitating infrastructure solutions such as flyovers. This research evaluated the Swami Vivekananda overpass in Rajkot based on traffic volume, delay, and fuel consumption metrics. Surveys indicated notable reductions in travel time and fuel consumption, validating the bridge's economic feasibility.

(Gohil & Bhatt, 2018, *International Journal of Research in Engineering, Science and Management*).

Building Information Modeling (BIM) is widely utilized in the construction industry, yet its application in infrastructure especially flyovers remain insufficiently leveraged. This research shows the application of BIM across various phases of a flyover project by utilizing conceptual, 3D, 4D, and 5D models. These models enhanced visualization, scheduling, and cost management, fostering collaboration and reducing design mistakes. A comparative study of two flyovers one traditional and the other utilizing BIM showed diminished delays, fewer misunderstandings, and enhanced efficiency with BIM inclusion. The study highlights the significance of involving stakeholders and utilizing real-time data for successful project execution.

(Kasar & Gaikwad, 2019, SSRN, <https://ssrn.com/abstract=3371507>).

As infrastructure projects become more complex, conventional techniques find it difficult to guarantee sustainable and economical bridge building. This research investigates the use of 6D BIM, merging 3D models with time, expense, and carbon footprint assessment throughout the lifecycle of the Donggou Bridge in China. The study shows that early BIM modeling improves collaboration among stakeholders, cost visibility, and management of environmental impacts. It also emphasizes that emissions during construction are primarily driven by embodied carbon from raw materials and equipment. Employing

BIM enhances constructability, minimizes errors, and supports life-cycle decision-making. The approach establishes a benchmark for utilizing 6D BIM in extensive infrastructure projects.

(Kaewunruen, Sresakoolchai, & Zhou, 2020, <https://doi.org/10.3390/su12062436>).

Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) are crucial instruments for assessing environmental and economic performance over a building's life span. This research emphasizes the growing importance of Building Information Modeling (BIM) in uniting these two methods for sustainable decision-making. The writers suggest a four-phase model that comprises establishing system limits, conducting inventory analysis, obtaining results, and optimizing. Three primary strategies for BIM integration are examined: retrieving data from BIM, connecting to external platforms, or incorporating LCA/LCC data straight into BIM. Autodesk Revit is the most frequently utilized software, typically combined with Athena or Tally. The research highlights the significance of Level of Development (LOD), specifically LOD 300, in precise LCA/LCC computations. An analysis of 36 case studies shows increased implementation in various building types and worldwide areas. The study finds that implementing BIM improves cost precision, lowers environmental effects, and streamlines sustainability evaluations. It also highlights issues like data standardization and emphasizes the need for additional tool development.

(Lu et al., 2021, *Journal of Cleaner Production*, <https://doi.org/10.1016/j.jclepro.2020.125438>).

This research examines the increasing use of Building Information Modeling (BIM) in infrastructure projects via a bibliometric analysis of 239 articles. The authors emphasize that BIM enhances productivity, cost estimation, and collaboration in infrastructure over conventional methods. Nevertheless, the rate of adoption is slower in infrastructure compared to vertical construction because of fragmented research, software constraints, and difficulties in data exchange. The document organizes BIM advantages into planning, execution, and operational phases, while also highlighting deficiencies like absence of standardization and dependable assessment techniques. It highlights the necessity for quantitative studies and more robust international cooperation networks

(Vilutienė et al., 2020, *Baltic Journal of Road and Bridge Engineering*, <https://doi.org/10.7250/bjrbe.2020-15.485>).

This document presents an extensive framework for performing benefit-cost analysis (BCA) in transportation initiatives. It characterizes BCA as a methodical evaluation of the costs and benefits of suggested options in relation to a reference scenario. The approach converts savings in travel time, reductions in vehicle operating costs, enhancements in safety, and environmental effects into financial values throughout the project's life cycle. The procedure involves planning, engineering assessment, financial evaluation, and concluding analysis via net present value and cost-benefit ratios. The guide also outlines methods for considering capital expenses, upcoming maintenance, and residual asset value. It highlights the importance of discounting future costs and benefits to align with current values. It is advisable to use practical tools such as travel models and cost spreadsheets for precise estimation. Conducting sensitivity analyses is recommended to tackle data uncertainty. The BCA method enhances decision-making by combining economic and non-economic effects of projects.

(Minnesota Department of Transportation, 2020) MnDOT BCA Guidance.

The document offers an organized framework for performing benefit-cost analysis (BCA) on highway projects. It clarifies how BCA assesses the economic choices between different project options and a standard scenario. The evaluation measures essential factors including journey duration, vehicle operation costs, safety results, and long-term infrastructure worth. It highlights planning, engineering evaluation, financial assessment, and analysis of outcomes through four key phases. The guide covers essential economic ideas, including discounting to reflect the time value of money. It emphasizes the significance of uniform data and assumptions throughout all scenarios. Sensitivity analysis is advised to handle uncertainty in variables such as traffic patterns. The paper additionally describes techniques for calculating net present value and benefit-cost ratios. It acts as a tool for making decisions throughout every stage of project development. Ultimately, the approach is flexible for additional transport sectors such as transit and aviation.

(Adapted from AASHTO's "User Benefit Analysis for Highways", August 2003. Retrieved from <https://www.dot.state.mn.us/planning/program/benefitcost.html>.)

This research examines the real-world application of Building Information Modeling (BIM) in infrastructure, concentrating on a flyover project located in Mumbai. Although BIM is prevalent in vertical construction, its application in horizontal projects is still restricted. The study illustrates the benefits of 5D BIM in scheduling, cost management, and teamwork when contrasted with traditional approaches. The research emphasizes that 3D, 4D, and 5D models enhance visualization, planning, and budget management. Expert opinions indicate improved collaboration and decreased communication barriers. The results indicate that BIM minimizes mistakes and budget excesses, showcasing its ability to revolutionize infrastructure growth in India by enhancing efficiency and clarity

Kasar, R. R., & Gaikwad, P. G. (n.d.). *Application of BIM: A Case of Flyover*. Sardar Patel College of Engineering. Retrieved from <https://ssrn.com/abstract=3371507>.

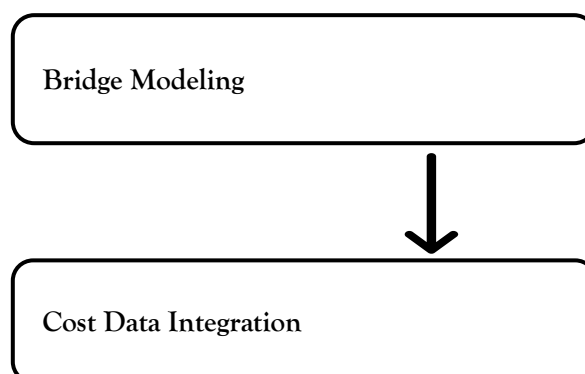
## METHODOLOGY

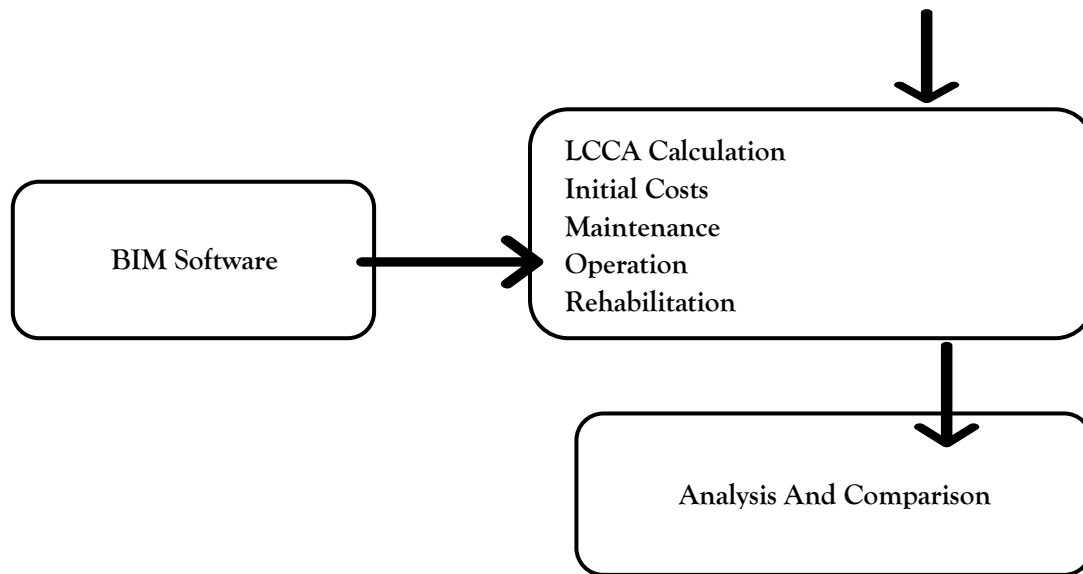
This research adopts a pragmatic, ethnographic methodology focused on observing, analyzing, and enhancing construction management via Building Information Modeling (BIM). The study was carried out by actively participating in two flyover projects in Mumbai—one employing traditional techniques and the other utilizing BIM-based modeling. The objective was to assess how effective the use of BIM models in various dimensions (3D, 4D, and 5D) is in infrastructure projects and to pinpoint the particular issues that BIM could assist in resolving.

### Research Structure

The approach was created in successive stages:

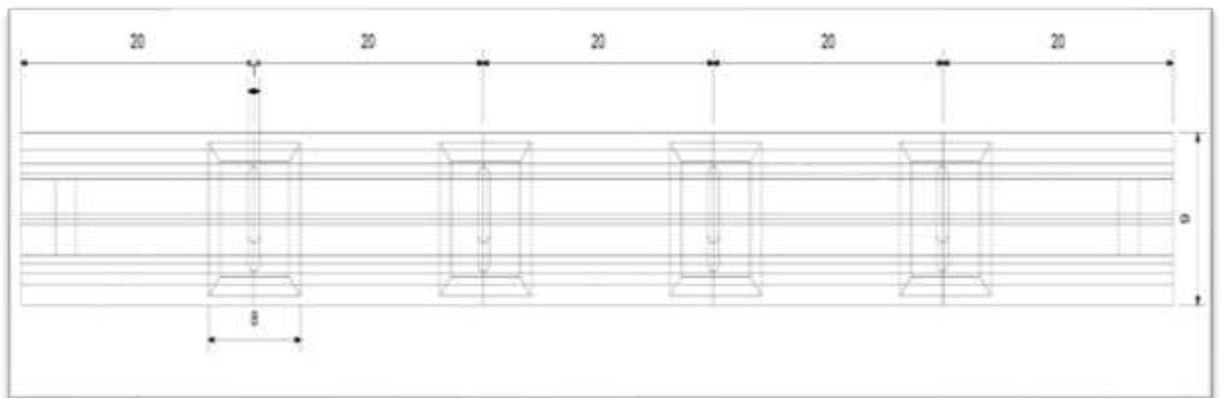
- I. Problem Identification – Early engagement in the traditional flyover initiative to comprehend current project difficulties.
- II. Solution Development – Crafting digital solutions grounded in identified problems.
- III. Execution – Deploying the suggested BIM models on the Flyover.
- IV. Monitoring and Evaluation – Participating in site assessment meetings, engaging with engineers, and improving the solutions.
- V. Impact Evaluation – Evaluating enhancements via stakeholder input and qualitative analysis.

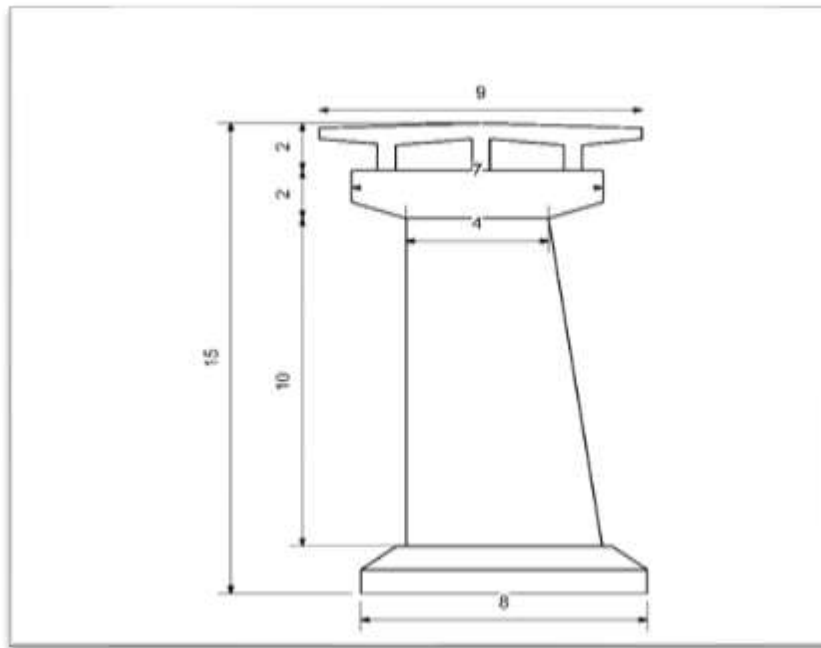




### Description of Pune Bridge

The bridge stretches 100 meters, connecting two supports situated on the Khadki and Emplacement sides. It comprises five equal sections of 20 meters, held up by vertical piers situated at 20-meter intervals throughout the length. Essential structural components consist of end abutments, intermediate supports, and deep pile foundations to guarantee stable load distribution to the subsoil. A dotted line represents the incline or tilt of the road, while height and section indicators assist in precise 3D modeling. This configuration facilitates the creation of a BIM model with Revit and assists in quantity assessment, lifecycle cost evaluation, and ongoing maintenance planning for a span of 75–100 years.





Pier Section of the Bridge

The bridge segment shows the load distribution system featuring PSC Tee Girders that support a bituminous deck surface, curbs, and protective railings. Loads are transferred via neoprene bearings and concrete pedestals to a pier cap of M30 grade. This cap transfers loads to an RCC pier shaft that broadens at the bottom for enhanced stability. The base consists of a reinforced concrete slab on M25 concrete fill that sits on rock. Elevation heights and water flow direction are indicated as well, assisting with BIM coordination. This comprehensive segment is critical for creating precise 3D BIM models and performing extended lifecycle cost assessments and maintenance strategies



Revit Model for LCCA

The model starts at the foundation base (FFRL 0.000), serving as the reference point for structural alignment in BIM. At FFRL 1.900, a reinforced concrete footing transfers loads from the pier shaft into the ground, resting on stable soil or rock. The pier shaft, constructed from RCC (likely M30 grade), is vertically tapered and reinforced to withstand vertical and lateral forces. Level 2 (FFRL 11.850) supports

the pier cap and bearings, while Level 5 (FFRL 17.950) defines the deck surface and features. These parametric levels enable precise BIM modeling, quantity estimation, phased construction planning, and lifecycle cost-based maintenance simulations.

### Detailed Life-Cycle Cost Analysis (LCCA) of the Pune Bridge

#### Step 1: Define Time Frame and Discount Rate

The evaluation presumes a 75-year operational life, in line with typical bridge lifespan projections. A 4% yearly discount rate represents typical capital costs and inflation in India as of June 2025. All anticipated costs are discounted to the reference year 2009, aligning with the bridge's initial construction year.

#### Step 2: Break Down Cost Components

The overall expense comprises an initial construction estimate of INR 50 million for a bridge measuring 100 meters. Annual routine maintenance expenses amount to INR 0.5 million. Significant repairs, planned every 25 years, incur expenses of INR 10 million for each occurrence. These take place three times over 75 years. The total cost for demolition and disposal at the conclusion of the service life amounts to INR 2 million.

#### Step 3: Calculate Present Value (PV) of Each Cost

The present value of future costs is calculated using the formula

$$pv = \frac{c}{(1+r)^t}$$

Where

- C = Future cost (in INR million)
- r = Discount rate (0.04)
- t = Time in years from the base year (2009).

#### Initial Construction Cost

- Occurs at year 0 (2009).
- PV = INR 50 million / (1 + 0.04)<sup>0</sup> = INR 50 million (no discounting for year 0).

#### Maintenance Cost

Annual cost of INR 0.5 million for 75 years.

Using the present value of an annuity formula

$$PV(\text{ANNUITY}) = C \times \frac{1 - (1+r)^{-n}}{r}$$

where n = number of years (75), C = annual cost (0.5), r = 0.04,

$$PV(\text{ANNUITY}) = 0.5 \times \frac{1 - (1 + 0.04)^{-75}}{0.04}$$

- $(1+0.04)^{75} = 4.148$
- $(1+0.04)^{-75} = 0.241$
- $1 - 0.241 = 0.759$
- $\frac{0.759}{0.04} = 18.975$
- PV = 0.5 × 18.975 ≈ INR 9.4875 million.

#### Major Repair Cost

- Three repairs at years 25, 50, and 75.
- PV for each repair
- Year 25 = PV =  $\frac{10}{(1+0.04)^{25}}$
- $(1.04)^{25} = 2.666$
- PV =  $\frac{10}{2.666} = 3.751$  INR Million

- Year 50 PV =  $\frac{10}{(1+0.04)^{50}}$
- $(1.04)^{50} = 7.107$
- PV =  $\frac{10}{7.107} = 1.407$  INR Million

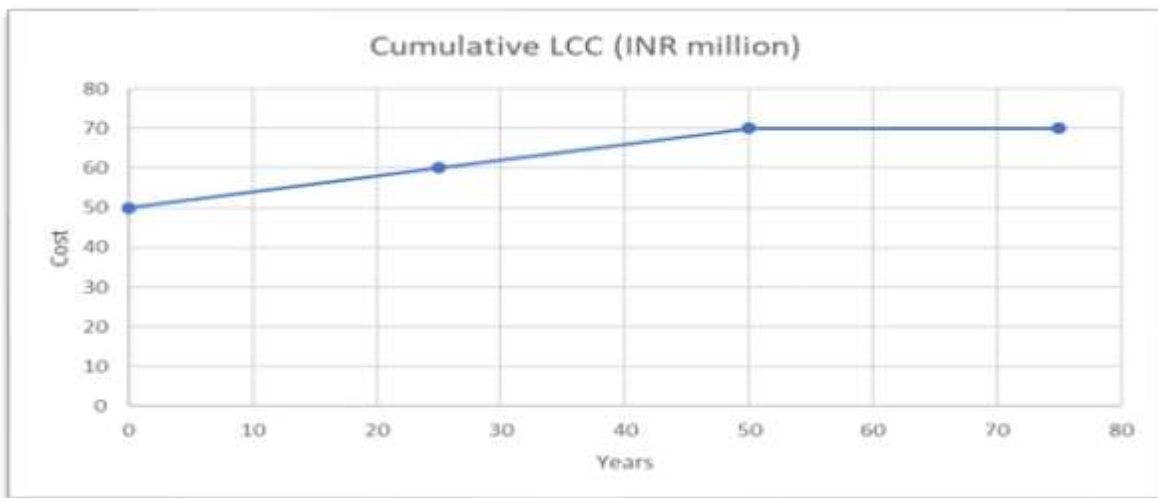
- Year 75 PV =  $\frac{10}{(1+0.04)^{75}}$
- $(1.04)^{75} = 4.148$
- PV =  $\frac{10}{4.148} = 2.411$  INR Million
- Total PV for repairs =  $3.751 + 1.407 + 2.411 \approx$  INR 7.569 million.

Disposal Cost

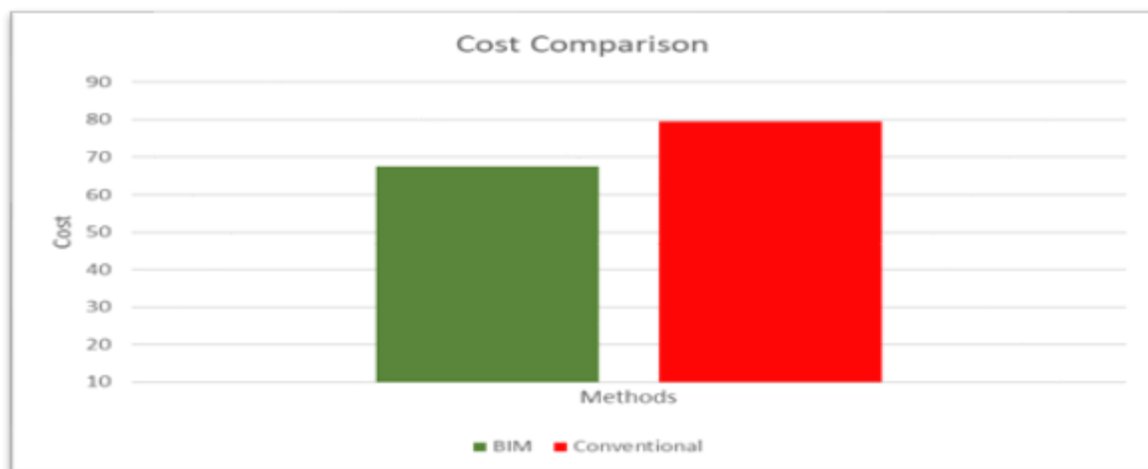
- Occurs at year 75.
- PV =  $\frac{2}{(1+0.04)^{75}}$
- $(1.04)^{75} = 4.148$
- PV =  $\frac{2}{4.148} = 0.482$  INR Million

Sum All Present Values

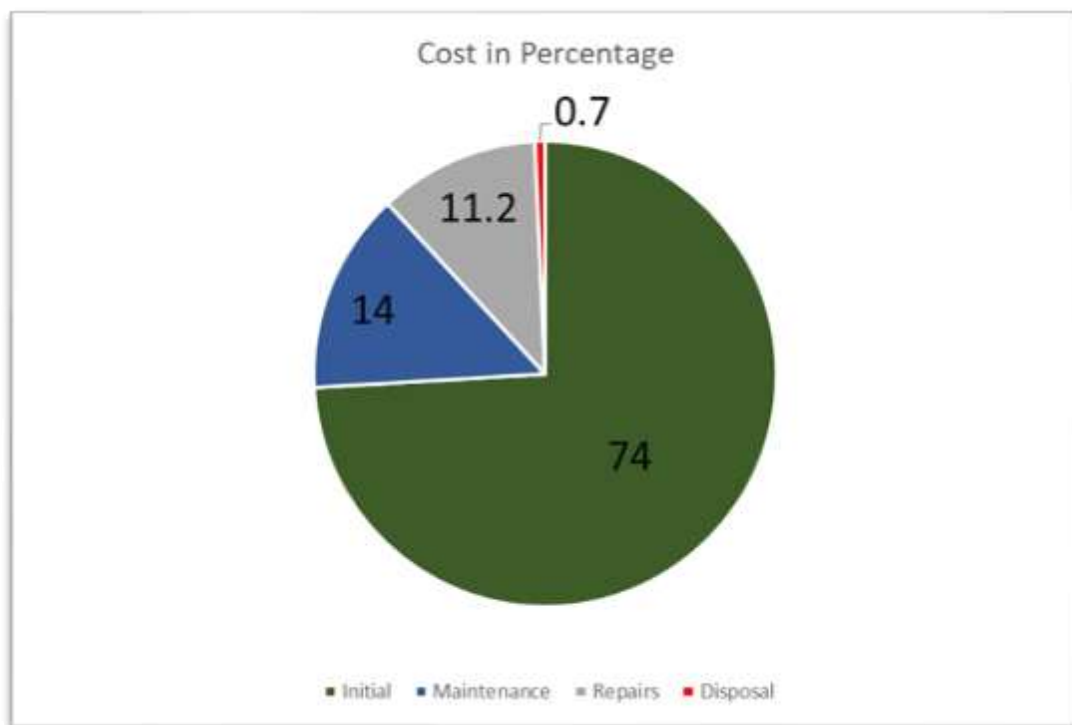
- Total LCC = PV of Initial Cost + PV of Maintenance + PV of Repairs + PV of Disposal.
- Total LCC =  $50 + 9.4875 + 7.569 + 0.482 \approx$  INR 67.5385 million.



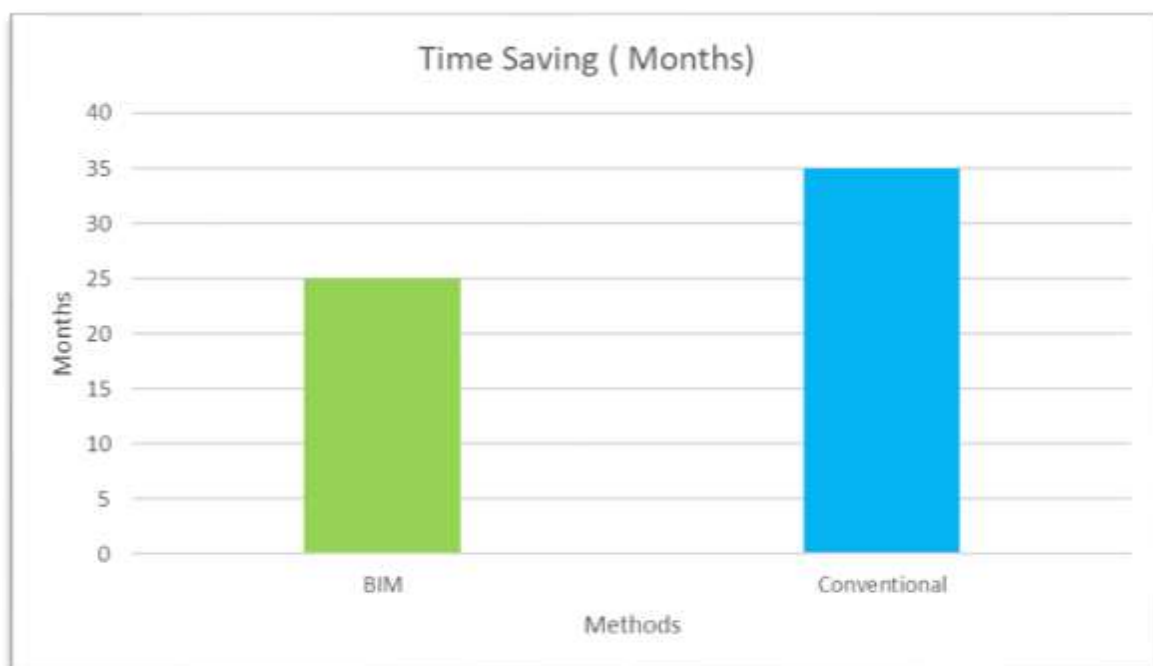
Cumulative Life-Cycle Cost Trajectory (Line Graph)



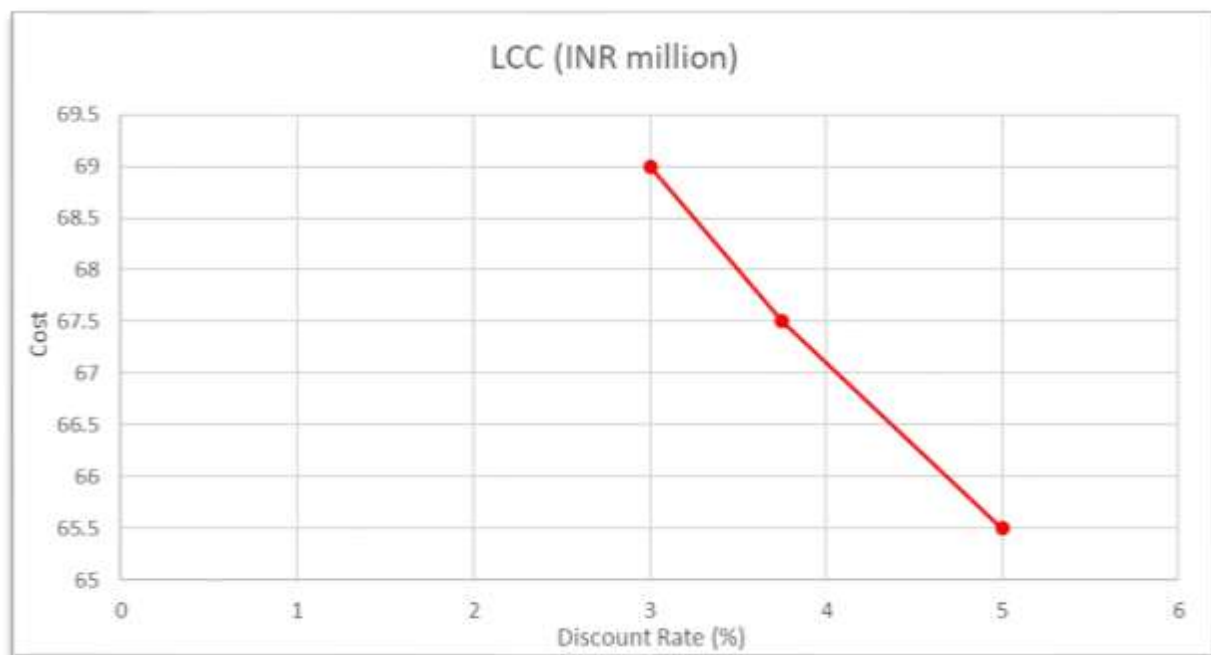
Cost Comparison: BIM vs. Conventional Methods (Bar Graph)



Life-Cycle Cost Breakdown (Pie Chart)



Time Savings with BIM (Bar Graph)



Sensitivity Analysis of Discount Rate (Line Graph)

## CONCLUSION

The timeline and cost analysis for bridge construction highlight considerable advantages of employing Building Information Modeling (BIM). Utilizing BIM, the project finishes in 27 months, showing a 10% reduction from the scheduled 30-month timeline. Conversely, traditional construction techniques face a 6-month delay, lengthening the project duration to 36 months. This holdup could stem from coordination problems, design mistakes, or inefficiencies caused by the lack of integrated modeling tools. From a cost perspective, BIM results in an overall project expenditure of around 67.54 million INR, encompassing construction, maintenance, repair, and end-of-life costs optimized via BIM's effective planning and implementation. In the meantime, the traditional method amounts to roughly 79.54 million INR, which includes the preliminary estimate, cost escalations, and current maintenance. The 12 million INR net cost difference and the 9-month time advantage highlight BIM's ability to enhance project delivery by reducing delays, improving coordination, and optimizing cost management throughout the bridge's lifecycle.

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