Building Information Modelling: Where EI (Engineering Intelligence) is Also Needed, not Just AI

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Abstract: The global rise of Building Information Modelling (BIM) has improved digital coordination across projects, yet its adoption is often misinterpreted as a software exercise rather than an engineering-centric process. This paper argues that BIM maturity is governed not by modelling tools but by Engineering Intelligence (EI)-the design judgement, code provisions & its awareness, constructability insight, sequencing logic, and interdisciplinary decision-making applied by engineers. Through evidence from Indian and international infrastructure, high-rise, industrial, and tunnelling projects, the study demonstrates that software alone identifies geometry, whereas EI interprets structural behaviour, prioritises clashes, ensures reinforcement feasibility, evaluates temporary works, and forecasts risks. Quantitative trends from real deployments indicate significant reductions in rework, congestion, sequencing delays, temporary works improvisation, and structural RFIs when EI governs BIM. The paper further highlights why field adoption often fails due to poor model usability despite high model availability, and how simplified access-through read-only viewers, QR-linked model locations, preset views and rugged tablets—enables successful site integration. Finally, it extends BIM's role beyond construction, illustrating how lifecycle continuity supports retrofitting, change of use, expansion, and safe decommissioning. The findings reinforce that BIM is not a replacement for engineering expertise but a framework that amplifies it; meaningful project performance is achieved only when digital workflows are driven by engineering intelligence rather than software proficiency.

Keywords: *Building Information Modelling (BIM); Engineering Intelligence (EI); Design Coordination; Constructability; 4D Sequencing; Risk Mitigation; Infrastructure Projects; Metro; Industrial Buildings.*

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I. INTRODUCTION

The contemporary perception of BIM in the construction industry is largely tool-centric. Many organizations equate BIM adoption with training personnel in software such as Revit, Navisworks, Tekla, or Synchro. However, the value of BIM is not extracted from 3D modelling alone but from the engineering decisions that models enable. Fundamentally, BIM is a process that integrates design, construction, and operational intelligence across a project's lifecycle. This integration is meaningful only when it is driven by individuals who understand structural behaviour, architectural intent, MEP design logic, construction methodology, safety, sequencing, and commercial considerations.

Global and Indian project experiences demonstrate that BIM deployment fails when it is implemented as a documentation exercise rather than a decision-support mechanism. Conversely, when engineering intelligence drives BIM - through early constructability input, clash prioritization, reinforcement feasibility checks, temporary works modelling, and risk forecasting - BIM strengthens multidisciplinary coordination and transforms project performance. Whether applied to a high-rise building in Mumbai, a metro alignment in Surat or Delhi, or a rail tunnel in the Hrishikesh-Karnprayag or even in UK, the common denominator of BIM success remains engineering competence, not just software proficiency.

II. BIM ADOPTION MISCONCEPTION — AI VS EI IN THE REAL WORLD

The acceleration of BIM adoption has created an illusion that improved project performance is inherently guaranteed by the use of modelling tools. In many organisations, BIM is interpreted as an extension of CAD, limited to 3D authoring and drawing extraction. This perspective reduces BIM to AI - Artificial Intelligence, where software produces outputs without necessarily improving engineering quality (*unless prompt*).

However, the real value of BIM emerges only when EI i.e. Engineering Intelligence governs digital processes. For

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instance, Navisworks can automatically generate hundreds of clashes in a coordinated model; yet, only an engineer with structural and construction understanding can differentiate a critical clash affecting safety or constructability from a non-critical clash tolerable on site. Similarly, Tekla can generate a dense reinforcement model, but determining whether rebar jamming will prevent concrete placement is a manual engineering assessment, not a digital output.

Thus, BIM is not a technological replacement for engineering skills; instead, it amplifies engineering capability when the right questions are asked and interpreted by qualified professionals. The risk arises when decision-making is delegated to software rather than engineering judgement.

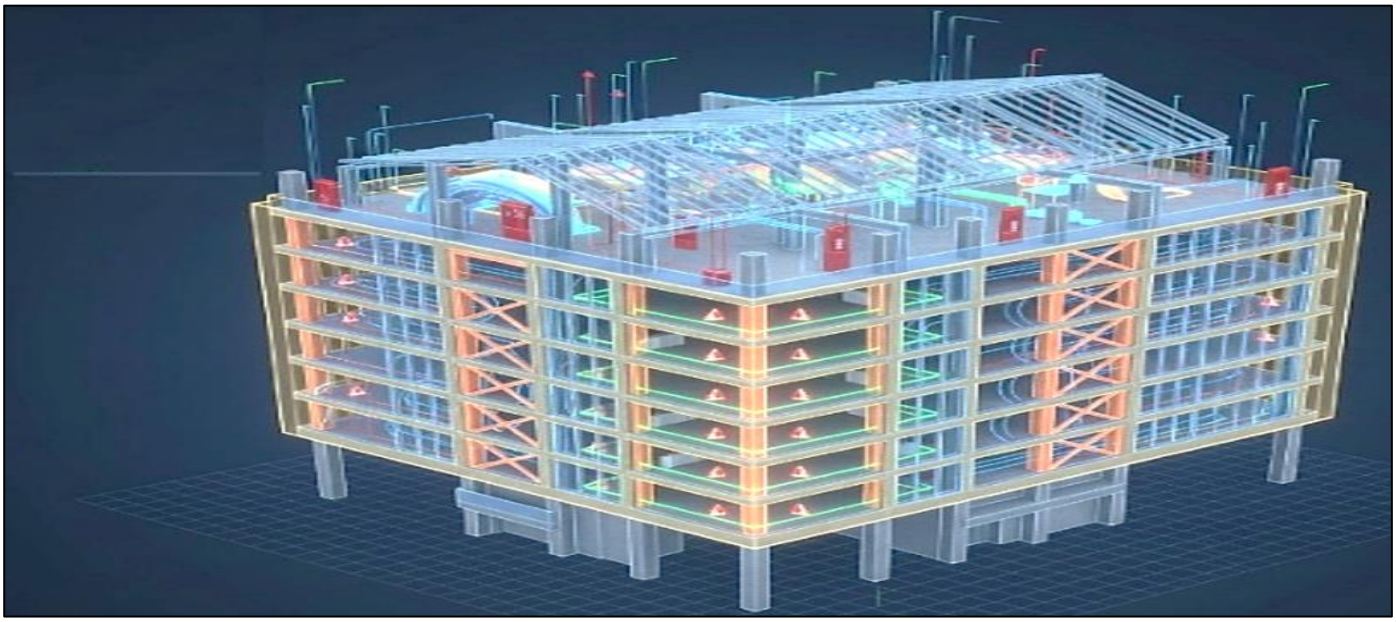
Fig 1- A Typ. AI- Generated Model, Requires EI

III. ROLE OF ENGINEERING INTELLIGENCE IN BIM

While BIM provides the digital environment for integrating design, analysis and coordination, its effectiveness ultimately depends on how intelligently engineers use that environment. The role of Engineering Intelligence (EI) is therefore not an abstract idea—it is the practical layer that converts digital information into correct engineering decisions. EI guides how a model is interpreted, how conflicts are prioritised, how constructability is evaluated, and how changes are understood in terms of real structural behaviour and site constraints. To explain this clearly, the influence of EI within BIM can be understood through seven foundational dimensions, or "pillars," that define where software automation ends and engineering judgment begins.

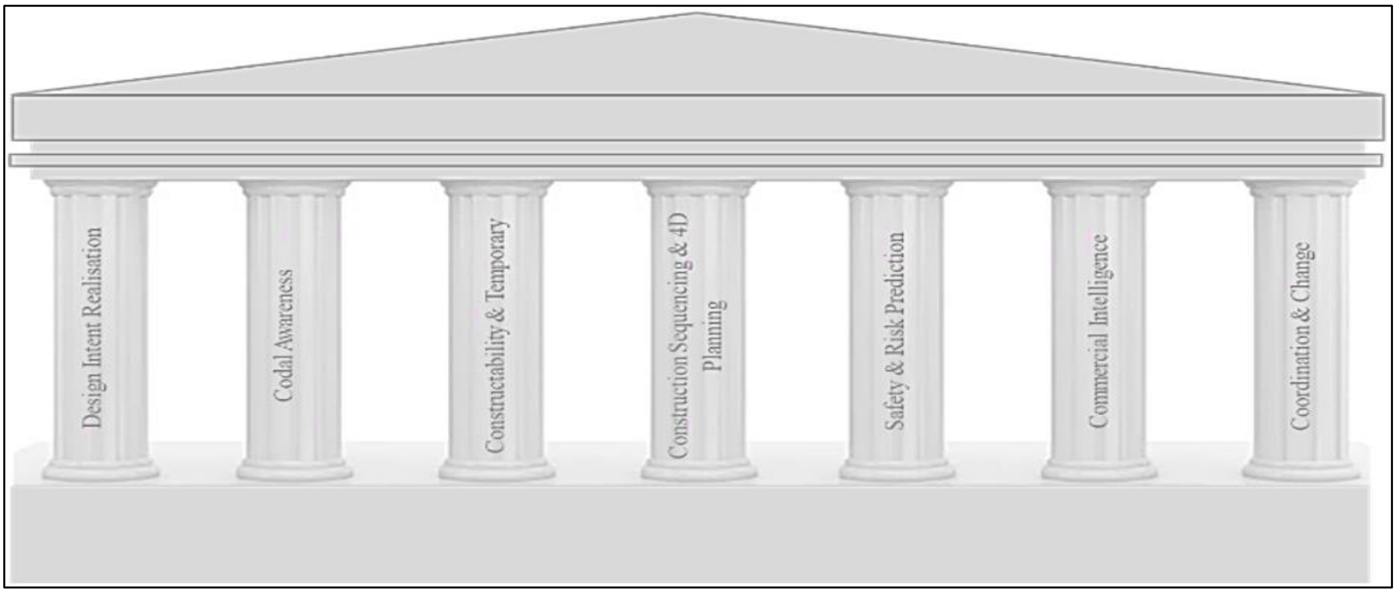

Fig 2 The Seven Pillars of EI-Driven BIM

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➢ *Pillar 1 – Design Intent Realization.*

Engineers must ensure the digital model reflects not just geometry but performance requirements — load paths, HVAC airflow behaviour, fire escape logic, waterproofing continuity, and vibration control.

➢ *Pillar 2 – Codal Awareness.*

BIM tools cannot determine compliance with IS, EN, ACI, BS, AS/NZS or NFPA standards. EI is required to validate cover requirements, fire separation, minimum riser diameters, rebar detailing, and floor loading.

➢ *Pillar 3 – Constructability & Temporary Works.*

Construction means methods — shuttering, heavy lifting, welding clearance, working platforms — do not automatically emerge from a 3D model. EI is necessary to model items that are not part of the permanent works but critical for execution.

➢ *Pillar 4 – True 4D Logic-Construction Sequencing & 4D Planning.*

A 4D simulation is meaningless unless it reflects real site logic such as crane locations, tower crane jumps, curing time of concrete, access sequence in tunnels, and material storage restrictions.

➢ *Pillar 5 – Safety & Risk Prediction.*

BIM supports hazard identification (Manual Handling, Working at Height, Hot Works, Confined Space) only when an engineer interprets the model from a safety perspective.

➢ *Pillar 6 – Commercial Intelligence.*

Quantity take-offs generated automatically do not contain wastage factors, cutting length loss, splicing ratios, or execution contingencies — EI governs these calculations.

➢ *Pillar 7 – Coordination & Change Control.*

EI identifies the impact of design or model changes — structural reanalysis, additional duct supports, shift in mechanical loads, ceiling elevation conflicts, or updated seismic provisions.

In short, BIM can visualise information, but only Engineering Intelligence can interpret it in the context of safety, constructability, standards, risk, sequencing and commercial outcomes.

IV. QUANTITATIVE IMPACT OF EI-DRIVEN BIM FROM A CIVIL & STRUCTURAL PERSPECTIVE

The impact of BIM is often measured using 4D/5D indicators, but for Civil/structural engineering, the most meaningful performance metrics come from design–site integration and constructability decision-making. Engineering Intelligence (EI) inside BIM can be quantified by evaluating structural accuracy, reinforcement feasibility, sequencing practicality, and risk reduction.

➢ *Structural Key Performance Indicators (KPI's), Influenced by EI.*

Civil and structural gains from EI-centric BIM typically fall under the following quantifiable domains:

- Reduction of Structural–MEP conflict affecting load path and stability.
- Minimization of reinforcement congestion and constructability issues.
- Improvement in concrete placement efficiency. (*no cold joints / no honeycombing*)
- Optimization of sequencing for PT, precast erection, or lifting of large structural or equipment elements.
- Reduction in temporary works rework and site improvisation.
- Reduction of RFIs (Request for Information) related to structural ambiguity.

The values presented below are indicative, probabilistic based and may vary across organisations, project types, contractual environments, and BIM maturity levels. Actual improvements depend on discipline coordination practices, engineering review rigor, and site execution culture.

Table 1 Metric Ranges Observed in Real Structural BIM Deployments

Structural Performance Indicator	Without EI (Tool-centric)	With EI (Engineering-driven BIM)	Improvement Trend
Congestion at beam–column joints	Up to 3–6 site revisions	Mostly resolved in pre-construction	70–85% reduction in site modifications
Clash affecting load transfer	Often detected late on site	Addressed at design coordination stage	60–80% reduction in structural rectification
Unbuildable reinforcement (no space for cover)	Frequent at deep beams and pile caps	Optimized during detailing review	~50–70% decrease in concreting delays
PT stressing interruptions	Stressing ports obstructed or inaccessible	EI-driven anchorage zone modelling	80–90% reduction in stressing delays
Temporary works improvisation on site	Scaffold / falsework redesigned mid-execution	Considered during model simulation	~40–65% time savings on heavy staging works
RFIs raised for structural interpretation	17–42 RFIs per block/zone	3–8 RFIs per block/zone	~65–75% reduction in structural RFIs

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➤ *EI as the Driver of Structural Gains*

Software alone detects geometry issues; structural EI detects buildability issues. Examples of EI-driven corrections that software cannot do automatically include:

- Prediction of long-term deflection redistribution without an engineer defining construction stages, stripping times, and PT stressing sequences.
- Enlarging concrete cover to comply with durability class.
- Ensuring lap lengths do not accumulate at the same section.
- Routing the ducts so they do not cut shear reinforcement.
- Avoiding congestion at diaphragm walls and pile caps.
- Verifying crane access for girder / segment erection.
- Positioning bracing and walers based on soil–structure interaction.
- Prioritizing clashes that affect load path rather than clearance alone.

So, these decisions depend on structural understanding and likely predictions of mishaps, not just on 3D visualization. And these topics represent only a fraction of EI-driven structural decision-making, and many more nuances remain beyond the scope of this short paper.

Table 2 Metrics Linked to Error Avoidance Rather Than Problem Solving

Stage	Cost of error correction
During design coordination	Very low
During reinforcement fixing	Moderate
During concreting	High
After loading / stressing	Extremely high (may lead to structural risk)

V. BIM ADOPTION — CHALLENGES & LESSONS LEARNED (INDIA AND GLOBAL)

The industry tends to measure BIM maturity using: LOD stages, Software used & Coordination reports. But the real maturity test is- Can the people who physically build the structure use BIM to make decisions faster than they can use 2D drawings?

Even when BIM models are highly developed, site teams frequently fall back to 2D drawings. This is not because field personnel (Site In-charge) lack interest in digital tools or do not understand their importance. It is because the operating ecosystem of a construction site is fundamentally different from the digital ecosystem of a design office. Site supervisors, foremen, fitters and shuttering crews work under constant time pressure, operate in dusty and noisy environments, and make dozens of rapid decisions every hour. So, they need information that can be accessed instantly, even in low-connectivity areas, without depending on login credentials, laptops or specialised software navigation. In such conditions, a printed GA Drawing becomes the quickest and most reliable decision tool — it opens immediately, it works without power, and it can be marked during discussions. Therefore, even when a BIM model contains far richer information, the site's daily tempo makes 2D the practical default.

Even when BIM models are highly developed, most site teams continue relying on 2D because "model availability" is not the same as "model usability." A model that requires panning, sectioning, isolating layers and searching coordinates is unrealistic for a supervisor on site with workers waiting for instructions.

From the first deviation onward, the BIM model begins drifting away from reality and gradually becomes only a reference instead of a construction-leading tool.

This pattern can be observed even on high-budget Indian and international projects. High-rise buildings with coordinated rebar models continued to experience beam–column congestion at site because foremen preferred highlighting conflicts on paper rather than checking clash-free detailing in the model. Slab openings for temporary excavation access were correctly shown in the BIM model but were relocated on site based on verbal instructions because accessing the model took longer than marking directly on drawings. Across all these cases, the BIM model was technically capable and theoretically useful, but it was not the fastest way to make a field decision. Therefore, construction reverted to 2D - not because of lack of technology, but because of a mismatch between digital workflows and real site conditions.

Projects that truly solved this issue did not train site teams to "learn BIM software." They simplified access: read-only viewers, QR codes that open the exact model location, preset camera views, direct RFI triggers inside the viewer, and rugged tablets that work outdoors.

Once BIM navigation became quicker than searching PDFs, field teams adopted it naturally — not because of enforcement, but because it saved time.

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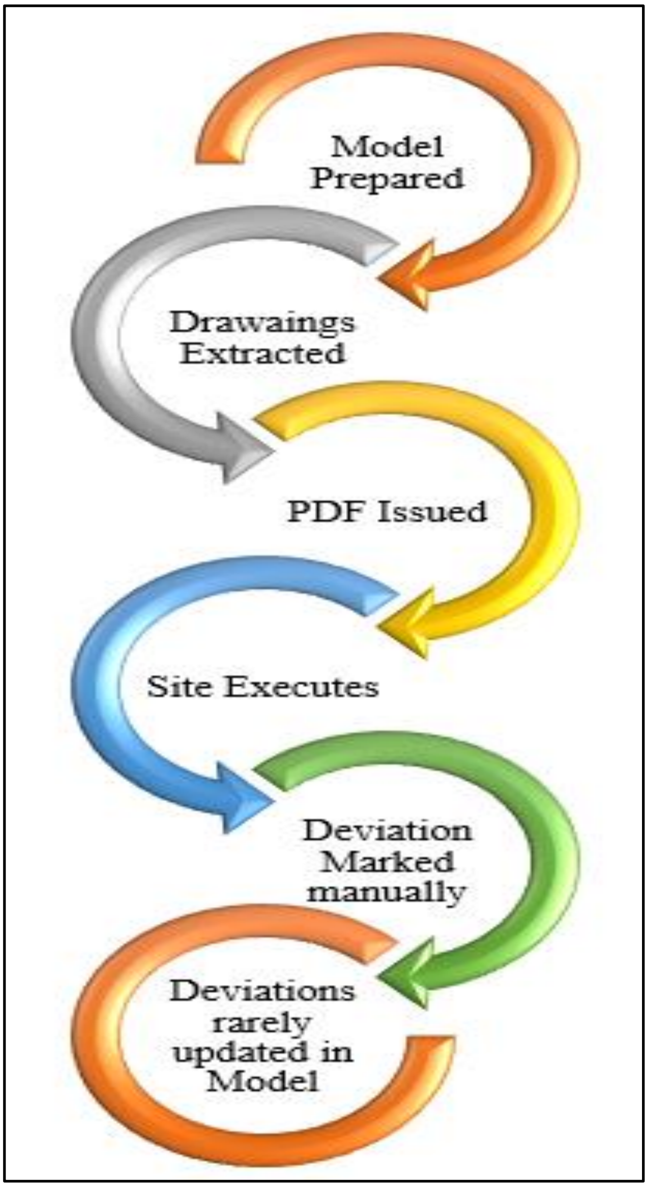

Fig 3 Loss of BIM Fidelity Across Construction Stages in Real Projects

Ultimately, BIM maturity is not defined by LOD or number of models, but by one practical measure:

➢ *Does the BIM Model Become the Primary Decision-Making Tool on the Site?*

If it accelerates decisions, BIM survives. If not, the field will always return to 2D - no matter how advanced the model is.

VI. BIM FOR LIFECYCLE CONTINUITY

In most organisations, BIM activity peaks during design and coordination and then reduces gradually as construction progresses. However, the real value of BIM emerges only when the model continues beyond construction and supports the operational lifespan of the asset. A model that stops at LOD-400 does not represent lifecycle maturity; lifecycle maturity begins when the BIM model transitions from "construction information" to "asset information."

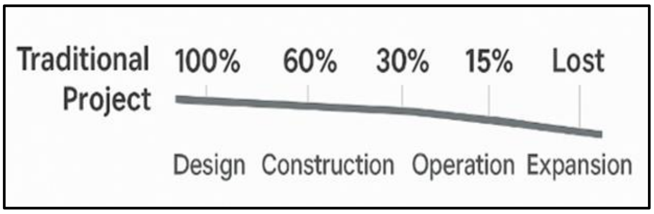

Fig 4 BIM Lifecycle Continuity in Traditional Projects

For civil and structural systems, this transition is especially critical because components that determine long-term performance — such as prestressed tendons, shear walls, bearings, expansion joints, waterproofing layers, soil–structure interfaces and critical fatigue zones — are usually concealed after commissioning. If these elements are not digitally captured and handed over properly, they become invisible for the next 40–60 years of service and maintenance, forcing engineers to depend on physical trials, core-cutting, manual drawings and fragmented records.

➢ *Lifecycle-Oriented BIM Addresses this Problem by Maintaining a Digital Memory of the Asset, Enabling Future Engineers to Verify:*

- Exact material grades and supplier traceability.
- Stressing logs and sequence records.
- Bearing and joint replacement cycles.
- Tendon sheath continuity and stressing pocket locations.
- Waterproofing layers and termination details.
- Fireproofing and corrosion protection systems.
- Embedment locations affecting future retrofits.
- Repair records, leak records and intervention history.

This is not theoretical - it is already operational globally. Scandinavian bridges track bearing replacement data through BIM-linked sensors; Japanese tunnels store bolting and convergence measurement history directly inside the digital model; Hong Kong high-rises embed fire-rating and asset tags linked to QR codes fixed on site.

India is also making progress: steel plants, airports and hydro projects increasingly demand BIM-based asset registers, warranty calendars, preventive maintenance logs and spare-part traceability. Large PPP highway projects are now pushing for BIM-based O&M manuals instead of conventional PDFs. The lifecycle impact becomes even stronger when the digital model is maintained during major building cycles, such as:

➢ *Retrofitting and Seismic Upgrades:*

A maintained BIM model reveals the actual reinforcement, layout, and material history of the structure, allowing engineers to design only the strengthening that is necessary—avoiding blind or excessive jacketing.

➢ *Change of use or Internal Re-Planning:*

With BIM holding the true load-carrying information, engineers can quickly identify which beams, slabs or walls can safely take additional loads without resorting to destructive testing.

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- *Facility Expansion or Vertical Extension:*
 Updated BIM records help determine which foundations, columns, and utilities were designed with spare capacity and which need modification, minimising re-excavation and reducing disruption.

- *End-of-Life Dismantling or Demolition*:
 BIM provides a reliable map of embedded reinforcement, utilities, hazardous materials and service routes, reducing risks and ensuring safe, planned decommissioning.

- *The Lifecycle Takeaway is Simple and Structural:*
 BIM does not replace drawings; BIM replaces the need for rediscovery. For infrastructure assets expected to run beyond 100 years — metro tunnels, dams, cable-stayed bridges, ports and industrial plants — the model is not just a design tool; it becomes the continuity thread across generations of engineers, preventing engineering memory loss. True lifecycle maturity is achieved only when BIM becomes the single source of truth from planning to demolition — not only for visibility, but for long-term operational decisions.

VII. PRACTICAL RECOMMENDATIONS

- Define Clear BIM Objectives Aligned with Engineering Intelligence (EI).
- Embed Engineering Intelligence (EI) in BIM Workflow.
- Develop a Lifecycle-Ready Model Strategy.
- Facilitate Site Usability & Field Adoption.
- Contractual & Commercial Alignment for BIM-EI.
- Governance, Standards & Training for EI-Driven BIM.

VIII. COST VS CAPABILITY: WHY DIGITAL CONSTRUCTION ADOPTION DIFFERS ACROSS PROJECT SCALES

Even though the construction industry has reached a point where advanced simulations, 4D phasing, and construction-stage analysis can precisely predict stresses, deformations, clashes, sequencing delays, and productivity bottlenecks, the question of economic practicality becomes the biggest filter for adoption. The challenge now is not whether the technology works - it absolutely does – but the question arise whether its benefits arrive before its cost becomes unjustifiable?

For mega-infrastructure projects, the justification is direct and measurable. In a cable-stayed bridge, delaying a stressing cycle, misjudging a cantilever moment balance, or sequencing a girder launch incorrectly can trigger rectification costs running into crores, not to mention schedule penalties.

For a TBM breakthrough shaft or a deep shoring system using multi-level walers and struts, even a single unanticipated deflection can jeopardise the entire excavation stability. In such environments, the investment in advanced modelling, parametric time–sequence analysis, and 4D planning pays back on Day 1 by reducing risk. The cost of error is so enormous that the cost of technology looks small.

The story flips in small residential and low-rise commercial projects. The margin of risk is low, the sequencing is simple, and the consequences of error are often manageable. A 4D simulation or construction-stage model for a G+3 building rarely influences decisions beyond what a competent site engineer can evaluate manually in minutes. Paying for dedicated modelers, licenses, cloud coordination platforms, and training brings no proportional return. The client does not demand it, the contractor cannot price it, and the execution teams do not feel the absence of it. The result is not resistance to technology — it is a rational economic rejection.

There is also a middle category — industrial sheds, IT parks, hotels, schools, etc. These projects want sophistication in drawings but typically do not guarantee the funds, manpower continuity, or decision-making discipline the technology requires. The cost is not just software; it is the time to model, time to verify, time to update after every change, and the need for skilled teams to run it consistently across agencies. If any of it one link breaks, the investment loses meaning. In short, adoption follows a simple rule:

"Where the cost of a mistake is higher than the cost of modelling, digital workflows win. Where it is the opposite, they remain optional."

In India, digital construction technology is not failing - it is simply waiting at the right price point and right project environment. Its true home today is infrastructure, where sequencing, construction loads, prestress stages, creep/shrinkage redistribution, soil–structure interaction, and tolerance-controlled temporary works dominate the project's fate. In that landscape, the money spent on digital workflows is not overhead - it is insurance.

MINDSET FOR YOUNG BIM BEGINNERS

A widespread misconception among freshers (engineers) entering BIM is that smart engineering decisions - cover thickness logic, reinforcement curtailment reasoning, connection detailing, crane positioning, duct routing, waterproofing continuity, or tendon stressing sequence — are gained "only with experience." This belief creates hesitation, fear of mistakes, and unnecessary dependency on seniors. But the reality is the opposite:

"Engineering Intelligence is not born from experience - it is formed from principles already taught in Diploma and Engineering."

The problem is that most students learn codes, design philosophy, and construction logic in isolated subjects - so they fail to see how these pieces connect inside a digital model. When a beginner starts BIM with only a software-first mindset, they become button operators: they click, but they don't think. But when they start BIM with an engineering-first mindset, every tool suddenly has meaning. The clues for

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Engineering Intelligence are not hidden — they already exist in the fundamentals student's study.

Table 3 Mapping Classroom Fundamentals to Real-World BIM Engineering Thinking

Classroom Learning	**Real-World BIM Thought Process**
Bending moment diagrams	Where should rebar be placed? How to curtail without losing capacity?
Load paths	Where must the beams align? Where walls shouldn't be cut by openings?
Service load combinations	Should slab deflection be checked for SIDL + finishes?
Poisson's ratio, shrinkage & creep	Time-dependent behaviour in staged construction models,
Soil mechanics & retaining structures	Walers & struts sequence in shoring, anchor prestress sequence.
Construction management	4D sequencing and temporary works selection.

➢ *To Accelerate Understanding, Beginners Should Develop 5 Habits from Day 1:*

- Whenever modelling anything, ask: "Why is this component shaped or placed this way structurally / architecturally or MEP-wise?
- Whenever software gives an automated output, verify it with codes, Outline Design specifications - not with blind trust.
- Whenever designing, think of how it will be built on site - not how it looks on screen.
- Whenever identifying clashes, evaluate consequences - not just count clashes.
- Whenever confused, refer to the code book first - not YouTube or the software manual *(unless its GUI understanding issue)*.

➢ *Concluding Remarks*

- The findings of this study reinforce that the effectiveness of BIM is not defined just by the sophistication of digital tools but by the engineering intelligence applied through them.
- It is not necessary to train workforce in modelling platforms but on simplifying access to information.
- BIM becomes a decision-driving tool only when navigating models is faster than searching drawings.
- Lifecycle continuity further expands BIM's value. A maintained model becomes the technical memory of the asset, reducing reliance on rediscovery during retrofitting, expansion, change of use, or safe decommissioning—particularly for long-span infrastructure with concealed structural behaviour.
- Finally, the economic dimension explains adoption patterns: BIM-intensive workflows naturally thrive where the cost of making a mistake is significantly higher than the cost of modelling.
- Digital information becomes meaningful only when interpreted through engineering intelligence.

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Abhijeet Vijay Gawai is a Civil & Structural Design Engineer at SGAWings Consultants, Mumbai. He holds a Diploma and Bachelor's degree in Civil Engineering, along with an International Certification in Building Information Modelling & Coordination. His experience spans metro, bridge, tunnel and building projects, with a focus on constructability, permanent and temporary works, sequencing logic, and risk-based design interpretation-most notably on the Surat Underground Metro, where he evaluated BIM models from a structural perspective. He has delivered technical lectures at various institutes on structural behaviour, construction-stage engineering and Timber structures. Passionate about advancing structural engineering, he aims to strengthen the integration of engineering fundamentals with modern BIM practices, ensuring digital tools enhance-rather than replace-sound engineering judgement.