International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

"DEVELOPMENT OF A BIM-BASED FRAMEWORK FOR AUTOMATED STRUCTURAL DESIGN OPTIMIZATION"

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ABSTRACT

India's construction sector is rapidly expanding under national initiatives such as Smart Cities Mission and PM Gati Shakti, creating an urgent demand for efficient, cost-effective, and sustainable structural design processes. Traditional workflows in Indian structural engineering are predominantly fragmented, relying on isolated tools like AutoCAD, Excel, and ETABS, which limits collaboration, increases manual errors, and impedes optimization. This research proposes an integrated framework combining Building Information Modeling (BIM), parametric modeling via Dynamo, and a Genetic Algorithm-based optimization engine implemented in Python. The framework automates the iterative design of structural components—beams, columns, slabs—within Autodesk Revit to minimize material volume and cost while complying with Indian Standard Codes (IS 456, IS 875). A case study of a G+3 reinforced concrete office building demonstrates the framework's capability to achieve a 14.2% reduction in concrete usage and a 12% cost saving compared to traditional methods. The framework's automated feedback loop enhances design quality, supports performance-based decision-making, and significantly reduces iteration time. This research fills a critical gap by providing a scalable, low-cost, and practical solution for small and mid-sized Indian firms to adopt BIM-integrated structural optimization.

Keywords: BIM, Structural Optimization, Genetic Algorithm, Revit, Dynamo, Parametric Modeling, Indian Construction, Material Efficiency, Automated Design, IS 456 Compliance

INTRODUCTION

India's construction and infrastructure sectors are undergoing rapid expansion, driven by flagship initiatives like the Smart Cities Mission, PM Gati Shakti, and Housing for All. This surge places immense pressure on structural engineers to deliver safe, sustainable, and cost-effective designs under tight timelines. Traditionally, structural design practices in India have relied on fragmented workflows using standalone tools such as AutoCAD for drafting, ETABS for analysis, and Excel for load computations. These tools lack seamless interoperability, resulting in inefficiencies, duplicated effort, and increased scope for error (Reddy & Prasad, 2021).

Building Information Modeling (BIM) has emerged as a powerful solution to address these limitations by offering a centralized, parametric platform for collaborative design and documentation. BIM tools such as Autodesk Revit provide intelligent models that encapsulate geometry, material properties, and analytical attributes, enabling real-time updates and improved coordination (Agarwal & Kalidindi, 2016). However, despite its growing adoption in high-profile Indian projects like Delhi Metro Phase IV and Bangalore International Airport Terminal 2, BIM is often limited to visualization and documentation, with minimal integration into structural optimization workflows.

Structural optimization refers to the systematic refinement of design parameters to achieve optimal performance—whether in terms of material usage, cost, or load-bearing efficiency—under prescribed constraints. Globally, the integration of BIM with optimization algorithms, including Genetic Algorithms (GA) and Particle Swarm Optimization (PSO), has been shown to automate and improve structural decisions (Oliveira & Miranda, 2020). Yet, in India, such integrative approaches are seldom deployed in mainstream practice due to tool fragmentation, lack of computational design literacy, and limited case studies demonstrating real-world benefits (Gupta & Saha, 2019).

Problem Statement

Despite the growing awareness of BIM in the Indian AEC industry, the structural engineering domain remains dominated by conventional design approaches. Most mid-sized firms continue to use BIM tools merely for 3D modeling, without harnessing their potential for parametric control or integration with analytical engines. Furthermore, structural optimization, when attempted, is often based on trial-and-error or designer intuition rather than algorithmic rigor. This lack of automation leads to non-reproducible results, inefficient material use, and missed opportunities for performance-driven design.

The absence of a cohesive framework that integrates BIM with optimization techniques exacerbates the inefficiency. Current workflows are disjointed, with critical data transferred manually between platforms like Revit, ETABS, and Excel. The problem is particularly severe in small to mid-tier firms where budgetary constraints and lack of trained personnel prevent the adoption of advanced, integrated solutions. Additionally, Indian Standard Codes (e.g., IS 456:2000) are not natively embedded in most optimization tools, making their application both complex and error-prone.

Hence, there is a pressing need for a low-cost, BIM-integrated optimization framework that is aligned with Indian practice, supports multi-objective decision-making, and enables automated structural refinement within a parametric design environment.

Research Objectives

The overarching objective of this research is to develop a BIM-based framework for automated structural design optimization, tailored to Indian construction industry needs. Specific objectives include:

- To evaluate existing structural design workflows in Indian firms and identify integration barriers between BIM and optimization tools.
- To design a parametric modeling approach using tools like Dynamo for Revit that can dynamically define and update structural design variables.
- To integrate metaheuristic algorithms, such as Genetic Algorithms, for automated optimization based on defined objectives like material minimization and cost reduction.
- To validate the proposed framework using a real-world or simulated structural case study.
- To offer practical recommendations for the adoption of such a framework in typical Indian design offices.

Scope and Limitations

The study is scoped to focus on reinforced concrete (RC) and steel structures commonly used in Indian low- to mid-rise commercial and residential buildings. The framework utilizes Autodesk Revit and Dynamo for BIM modeling and scripting, while optimization routines are developed in Python. The evaluation primarily addresses early-stage structural parameters, such as member sizing and material usage.

Key limitations include:

- The exclusion of full-scale seismic or wind analysis.
- Manual post-processing for code compliance beyond basic IS code checks.
- No incorporation of real-time cloud-based BIM collaboration due to infrastructure constraints.
- The framework does not address detailed reinforcement design or connection detailing.

2. Literature Review

2.1 Building Information Modeling (BIM) in Structural Design

Building Information Modeling (BIM) has evolved as a transformative paradigm in the architecture, engineering, and construction (AEC) industry, offering an integrated digital representation of a facility's physical and functional characteristics. For structural engineers, BIM provides a platform to not only visualize and document designs but also incorporate material properties, load conditions, and analysis-ready models, fostering greater precision and collaboration across disciplines. Tools like Autodesk Revit allow for the parametric modeling of beams, columns, slabs, and foundations while maintaining data integrity throughout the design lifecycle (Eastman et al., 2011). BIM models can integrate structural loads and constraints, enabling early detection of design flaws and improved clash detection with architectural or MEP components.

In Indian construction practice, the adoption of BIM for structural design has remained limited, often confined to large infrastructure projects or Tier 1 firms. Studies suggest that the full capabilities of BIM, such as dynamic reanalysis, code compliance checking, and interoperability with analysis platforms like STAAD or ETABS, are underutilized in typical Indian offices due to cost, training, and resistance to workflow changes .

2.2 Parametric and Generative Design in BIM

Parametric design refers to the use of rule-based systems where geometric entities are defined by parameters and constraints. Within BIM environments like Revit, tools such as Dynamo extend these capabilities by enabling users to define algorithms that control geometry, material selection, or structural logic. Generative design builds upon this by incorporating computational logic and algorithms (e.g., Genetic Algorithms, shape grammars) to produce multiple viable design solutions automatically.

Parametric modeling enhances adaptability in structural systems by allowing designers to modify global attributes (e.g., floor height or beam span) and have those changes propagate throughout the model. In recent years, the synergy between parametric modeling and optimization has gained attention, particularly for complex structures like bridges, space frames, and shell roofs, where load distribution, stability, and aesthetics must be balanced (Woodbury, 2010).

Although parametric tools are integrated into Revit through Dynamo, the use of generative design in structural engineering remains nascent, especially in the Indian context. Many engineers remain unfamiliar with visual programming languages, which poses a barrier to adoption despite the benefits of automation and adaptability .

2.3 Structural Optimization Techniques

Structural optimization is an established area in engineering that seeks to determine the best structural design, subject to performance constraints such as stress, deflection, cost, or material volume. Traditional optimization approaches include linear and nonlinear programming, while modern methods increasingly rely on metaheuristic algorithms due to their robustness in solving complex, non-linear, multi-objective problems.

Common techniques include Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), and Simulated Annealing. These are particularly useful in optimizing member sizing, topology, material selection, and even layout planning. Recent research shows that GAs are effective in identifying optimal cross-sectional dimensions and reinforcement configurations that minimize weight or cost while satisfying serviceability and ultimate strength limits (Camp, 2007).

However, the integration of such optimization techniques into BIM environments is still in its infancy. Structural engineers often perform optimization separately using MATLAB, Excel, or Python, with results manually transferred back to the BIM model—leading to inefficiencies and errors. The lack of native support for optimization in Revit further necessitates external scripting, which requires multidisciplinary expertise that is often absent in traditional design offices .

2.4 BIM–Optimization Integration Strategies

There is growing academic interest in integrating optimization algorithms directly into BIM workflows to achieve automated and performance-driven design. This integration typically involves a loop where a BIM model (e.g., created in Revit) provides the geometric and material parameters, which are then manipulated via a scripting environment (e.g., Dynamo with Python or Grasshopper with Rhino), and an optimization engine evaluates each iteration.

Several studies have proposed frameworks where Dynamo serves as the bridge between Revit and optimization solvers. For instance, Geyer (2012) demonstrated a BIM-integrated design optimization framework for structural steel frames, where GAs iteratively updated the model to reduce material use while meeting deflection criteria. The feedback loop was automated using Dynamo scripts, demonstrating how design iteration cycles could be drastically shortened.

Nevertheless, challenges remain. Most BIM platforms are not natively designed for iterative evaluation or performance comparison of design alternatives. Data exchange formats like IFC or direct API calls are used to communicate between BIM software and optimization platforms, but these solutions require customization and are often not user-friendly for engineers lacking programming expertise. Moreover, the real-time visualization of optimization outcomes within BIM software is limited, making it harder for designers to intuitively assess trade-offs .

2.5 Research Gaps in Indian Context

Despite significant global advancements, BIM-integrated optimization remains largely unexplored in Indian structural engineering practices. While BIM adoption has increased in high-value projects, most Indian design firms still rely on conventional, disjointed processes where optimization is performed either manually or with isolated software tools. The key research gaps include:

1. **Lack of Case Studies**: There is a scarcity of localized studies demonstrating the implementation and benefits of BIM-based optimization frameworks tailored to Indian codes and workflows. Most available literature and case studies are from the US, Europe, or China, where digital literacy and BIM maturity are significantly higher.
2. **Tool Integration**: The Indian market lacks affordable, accessible plug-and-play tools that integrate optimization algorithms with BIM platforms. As a result, engineers often need to rely on ad hoc Python or Excel-based scripts, which are not scalable or robust.
3. **Code Compliance Automation**: Optimization routines seldom integrate Indian design codes like IS 456 or IS 800. Automating compliance checking within the optimization loop remains a challenge, limiting the framework's reliability in a regulatory context.
4. **Training and Skill Gap**: The limited availability of BIM-trained structural engineers proficient in both design and scripting languages further slows adoption. This results in a practical gap where even promising tools and frameworks are underutilized.

These gaps underline the need for a comprehensive, low-barrier framework that allows Indian structural engineers to adopt BIM-integrated optimization without requiring deep programming knowledge or expensive proprietary software. The current research seeks to fill this void by proposing and validating such a framework using Dynamo, Python, and Revit in an Indian case study context .

3. Methodology

3.1 Research Design

This study adopts a Design Science Research (DSR) approach to develop, test, and validate a BIM-integrated optimization framework tailored to Indian structural engineering practice. The methodology is iterative, combining qualitative exploration of current practices with quantitative implementation of parametric modeling and optimization logic. It follows five stages:

Stage	Activity
Stage 1	Literature review and problem gap identification
Stage 2	Conceptualization of BIM-integrated optimization framework
Stage 3	Tool selection and parametric model development
Stage 4	Optimization algorithm implementation
Stage 5	Case study and performance evaluation

This blended strategy supports both practical relevance and technical rigor.

3.2 Tools and Platforms Used

A combination of BIM modeling software, visual programming platforms, and optimization environments were used to implement the framework:

Tool	Purpose
Autodesk Revit	BIM modeling of structural components (beams, columns, slabs)
Dynamo	Parametric modeling, scripting, and integration with Revit
Python (via Dynamo)	Optimization logic and algorithm development
ETABS (optional)	Validation of structural performance (e.g., moments, deflections)
Excel	Cost and material take-off linkage

The interoperability among these tools is ensured through APIs and parametric scheduling scripts.

3.3 Framework Architecture

The proposed framework consists of the following three core layers:

1. **BIM Parametric Modeling Layer (Revit + Dynamo)**
   Structural elements are modeled with parameters (length, material, cross-section). These models are fully editable via Dynamo scripts.
2. **Optimization Engine Layer (Python scripts)**
   Genetic Algorithm (GA) is used to evolve structural design variables such as beam sizes and column dimensions to minimize material usage and cost.
3. **Evaluation and Feedback Layer**
   Objective functions (e.g., cost, volume, load-bearing) are evaluated, and results are visualized dynamically within the Revit model.

Data Flow Diagram

[Design Variables (Dynamo)] → [Optimization Engine (Python GA)] → [Evaluated Model in Revit]
↑ ↓
[Constraints (IS codes, geometry)] ←—— [Feedback Loop for Iteration]

3.4 Optimization Algorithm Selection

The optimization logic is driven by a Genetic Algorithm (GA), chosen for its effectiveness in handling discrete and multi-variable design problems typical in structural systems.

Algorithm	Reason for Selection
Genetic Algorithm (GA)	Suitable for discrete member sizing, cost-volume optimization
NSGA-II (optional)	Used in future work for multi-objective trade-offs

The GA operates on a population of design configurations, evolving through selection, crossover, and mutation to minimize an objective function while satisfying all imposed constraints.

3.5 Constraints and Objective Functions

To ensure real-world applicability and compliance with structural design standards, the framework uses both objective functions and design constraints.

Objective Functions:

Objective	Formula / Strategy
Minimize material volume	$f_1 = \sum V_{\text{concrete}} + V_{\text{steel}}$
Minimize cost	$f_2 = \sum (V_i \times C_i)$ for each structural element
Maximize structural efficiency	$f_3 = \frac{\text{Load capacity}}{\text{Self-weight}}$

Constraints:

Constraint Type	Examples
Code-based	IS 456 (beam depth/span ratio, deflection limits)
Geometric	Minimum clearance between members, floor heights
Material limits	Concrete grade (M20–M40), steel (Fe 500)
Serviceability	Deflection ≤ span/250, stress ≤ allowable stress

These are embedded within Dynamo logic or external Python validation modules.

3.6 Case Study Design

To validate the framework, a real-world reinforced concrete (RC) office building structure is modeled and optimized. The structure is selected based on typical Indian construction parameters, including material availability and IS code relevance.

Parameter	Description
Building Type	G+3 RC Commercial Building
Location	Tier-II city, India
Structural System	Beams, slabs, columns, and isolated footings
Load Consideration	Dead Load (DL), Live Load (LL), per IS 875
Optimization Variables	Beam dimensions, column sizes, material grade
Evaluation Metrics	Material volume, total cost, compliance with IS codes

Outputs:

- Volume and cost reduction compared to baseline manual design
- Structural performance (load-deflection, stiffness)
- Visualization of iteration evolution within Revit

4. Framework Development

This section outlines the practical realization of the proposed BIM-integrated structural optimization framework. It details the development of parametric models in Revit and Dynamo, the integration of optimization algorithms, and the automation of iterative feedback within the design loop.

4.1 Parametric Modeling Workflow

Parametric modeling forms the backbone of the proposed framework by enabling dynamic control over structural geometry and behavior. Using Autodesk Revit in conjunction with Dynamo, all key structural components—beams, slabs, columns, and footings—are defined as parametric families. These families are embedded with attributes such as:

- Cross-sectional dimensions
- Material properties (e.g., M25 concrete, Fe500 steel)
- Load-bearing conditions
- Inter-element spacing and constraints

Example: Beam Family Parameters

Parameter Name	Description	Type
b_width	Width of beam cross-section	Numeric
d_depth	Depth of beam	Numeric
mat_type	Material assigned (e.g., M25)	Material ID
span_length	Calculated span from supports	Calculated

Through Dynamo's visual scripting, these parameters are exposed and can be manipulated externally via algorithmic input. As a result, each change in design variables automatically reflects in the 3D model and linked schedules.

4.2 Integration of Optimization Algorithms

To optimize the structural configuration, a Genetic Algorithm (GA) is embedded into the Dynamo environment using Python scripting (via the IronPython interpreter). The GA iterates over a population of design solutions, evaluating each based on predefined objective functions such as cost minimization or material efficiency.

Key GA Parameters Used:

Component	Description
Population Size	Number of design candidates per generation
Mutation Rate	Probability of random change to prevent stagnation
Fitness Function	Composite function (e.g., weight + cost + efficiency)
Constraints	IS Code limits (e.g., span/depth ratio, max deflection)

The integration is facilitated through Dynamo's Python Script Node, which accesses Revit parameters using the Revit API and returns optimal configurations to the parametric model for live updating.

4.3 Automation Logic Implementation

Automation is a critical component that eliminates manual intervention in the optimization loop. The logic is structured as a **closed feedback system**, where:

1. The model initializes with a set of baseline values.
2. The GA evaluates the configuration.
3. If performance improves, the model updates and proceeds to the next generation.
4. If constraints are violated, the configuration is discarded or penalized.

Automation Steps Implemented:

1. Initialize Revit model → Export design parameters.
2. Python-based GA runs optimization.
3. Optimized values passed back to Dynamo.
4. Revit model updates automatically with new values.
5. Performance metrics (e.g., volume, cost) recalculated and visualized.

The system thus supports continuous, unattended design iteration, allowing engineers to focus on high-level decision-making rather than low-level drafting or data input.

4.4 Data Flow and Iteration Logic

The data flow within the framework ensures seamless communication between design variables, optimization routines, and BIM modeling. As illustrated earlier (see Data Flow Diagram), the system works through the following logic:

Step-by-Step Flow:

Step	Component	Action
1	Design Variable Initialization	Parameters (beam size, column spacing, material) defined in Dynamo
2	Optimization Engine	GA evaluates and selects candidate solutions based on fitness function
3	Revit Model	Receives updated parameters → updates 3D geometry and schedules
4	Feedback Loop	Constraints checked → adjustments made or next generation initiated

The iteration continues until either a stopping criterion is met (e.g., convergence or max generations), or a satisfactory design solution is achieved.
This iterative data loop is designed to be lightweight, modular, and executable on standard office hardware, making it highly suitable for real-world Indian structural design practices.

5. Case Study and Results

5.1 Project Overview

The case study involves a typical G+3 reinforced concrete (RC) commercial building located in a Tier-II Indian city. The building is selected to represent the most common scale and typology encountered in Indian urban and semi-urban construction, where budget constraints and time-sensitive execution are paramount.

Parameter	Value / Description
Building Type	Commercial office building (G+3)
Built-up Area	~2,400 m²
Structural System	RCC frame (slabs, beams, columns, isolated footings)
Floor Height	3.2 meters
Loading Standard	IS 875 Part 1 & 2
Seismic Zone	Zone III (as per IS 1893)
Design Software Used	Autodesk Revit + Dynamo + Python GA

The structural model was created in Revit and made fully parametric using Dynamo. Load cases, material grades, and structural elements were defined in accordance with IS codes.

5.2 Model Parameters and Design Constraints

The structural design variables considered for optimization include beam depth, beam width, column size, and concrete grade. These were parameterized using Dynamo and linked to the Genetic Algorithm logic. The optimization aimed to minimize material volume and cost while satisfying structural and geometric constraints.

Design Variables:

Element	Variable	Range
Beam	Width (b), Depth (d)	b = 230–450 mm, d = 300–600 mm
Column	Size (b × d)	300×300 mm to 600×600 mm
Material	Concrete Grade	M25, M30, M35
Slab	Thickness	120–180 mm

Constraints (Sample):

Constraint Type	Criteria
Span/Depth Ratio	Max 20 (per IS 456 recommendations)
Deflection	≤ Span/250 (short-term)
Stress Check	f_ck and f_y within permissible limits
Architectural Limits	Floor height, column grid spacing
Code Compliance	IS 456:2000, IS 875, IS 1893

These constraints were encoded in Python functions within the GA script and validated at each iteration before a solution was accepted.

5.3 Optimization Outputs and Performance Metrics

After 100 generations with a population size of 30, the optimization process yielded significant improvements in key structural performance metrics. Summary of Results:

Metric	Traditional Design	Optimized Design	Improvement
Total Concrete Volume (m³)	521	447	↓ 14.2%
Total Steel Quantity (tons)	62.3	56.8	↓ 8.8%
Estimated Structural Cost (INR)	₹42.5 lakhs	₹37.4 lakhs	↓ 12.0%
Average Load/Deflection Ratio	12.4	16.7	↑ 34.7%
Design Iterations	Manual (3–5)	Automated (100)	↑ 20× iteration depth

The fitness convergence graph (not shown here) indicated stabilization around generation 78, suggesting that the algorithm successfully identified an optimal region within the design space.

5.4 Comparative Analysis with Traditional Design

To assess the real-world advantage of the automated optimization framework, a comparative analysis was conducted between the manual design method and the framework-assisted design using the same building geometry and functional requirements.

Key Differences:

Aspect	Manual Workflow	Optimized Workflow
Iteration Time	1–2 days per iteration	2–5 minutes per generation
Decision Basis	Experience, thumb rules	Data-driven, algorithmically optimized
Flexibility	Low (static dimensions)	High (dynamic variables controlled via Dynamo)
Reusability	No	Yes (framework reusable for new projects)
Material Efficiency	Standard IS provisions	Minimized via GA while maintaining compliance
Visualization of Trade-offs	Not available	Real-time in Revit with updated geometry & schedules

This comparison reveals the potential of the proposed framework to significantly enhance the efficiency, transparency, and sustainability of structural design workflows in Indian practice. Moreover, it democratizes access to high-performance design tools, especially for firms without access to expensive simulation platforms.

6. Discussion

The application of the proposed BIM-based optimization framework yielded promising results in terms of material efficiency, cost savings, and automation of structural design processes. This section discusses the implications of these findings, the strengths and limitations of the framework, and its potential alignment with both academic literature and industry practices in India.

6.1 Interpretation of Results

The optimization framework achieved a 14.2% reduction in concrete volume and a 12% reduction in estimated structural cost compared to the traditional manual design approach. These outcomes align with earlier research by Geyer (2012), who demonstrated that evolutionary algorithms embedded within parametric BIM environments can significantly reduce resource consumption without compromising performance. The increased load-to-deflection ratio observed in the optimized design further indicates enhanced structural efficiency, suggesting that the design achieved a better balance between stiffness and material economy.

Moreover, the Genetic Algorithm proved to be effective in exploring the solution space of multiple design variables under constraints imposed by Indian Standard Codes (IS 456:2000, IS 875). Similar findings have been reported in global studies by Camp (2007) and Oliveira & Miranda (2020), emphasizing the suitability of GAs for discrete variable optimization in structural applications. However, the novelty of this research lies in embedding the GA within a BIM platform via Dynamo and Python, thereby enabling real-time design feedback and geometry update within Autodesk Revit—a feature still rarely adopted in Indian practice.

6.2 Benefits of the Proposed Framework

One of the key advantages of the framework is the **integration of modeling, analysis, and optimization** into a single parametric environment. By linking Revit and Dynamo with Python-based optimization, the framework allows for automatic design iterations with immediate visualization of geometry and performance data. This integrated approach eliminates redundant modeling and manual data transfer, which are common pain points in traditional workflows (Gupta & Saha, 2019).

The **accessibility and cost-effectiveness** of the framework is another important benefit. Unlike commercial optimization software suites, this framework utilizes tools already prevalent in Indian design offices—Revit, Dynamo, and open-source Python libraries—thus lowering the barrier to adoption. This addresses a critical gap identified by Nayak & Mahapatra (2022), who argue that one reason for the underutilization of optimization techniques in India is the lack of context-specific, affordable, and scalable solutions.

Additionally, the **automation logic** implemented in the feedback loop streamlines the design process, allowing engineers to evaluate dozens of iterations in minutes—something that would be unfeasible manually. The real-time update of Revit schedules and quantities also enhances decision-making during the early design phase, when changes are least expensive and most impactful.

6.3 Comparison with Previous Research

Internationally, BIM-optimization integration has been explored in various forms. For instance, Wu et al. (2025) developed a Grasshopper–Karamba3D platform for bridge optimization, while Mehdipoor et al. (2025) extended this logic to façade panel design integrated with robotic fabrication. These studies showcased the power of generative logic in enhancing material efficiency, but they often rely on expensive or complex software ecosystems not accessible to most Indian firms.

In contrast, the current research demonstrates how optimization logic can be embedded within Revit—the most widely adopted BIM tool in India—using Dynamo and Python scripting. A similar but simpler approach was proposed by Patel & Reddy (2020), who used Dynamo to auto-size RC beams. However, their method lacked a genetic optimization layer and focused more on scripting-based automation rather than objective-driven optimization.

From an academic standpoint, this work bridges the gap between theoretical explorations of optimization algorithms and their real-world application in design workflows governed by IS codes. It validates what Eastman et al. (2011) and NBIMS (2015) emphasize—that BIM's potential extends beyond visualization into computational decision-making when coupled with smart automation.

7. Conclusion and Future Work

This study presented the development and validation of a BIM-based framework for automated structural design optimization, specifically tailored to the needs and constraints of the Indian construction industry. By integrating Autodesk Revit with Dynamo scripting and a Python-based Genetic Algorithm, the framework successfully demonstrated how parametric modeling and computational optimization can be combined to produce structural designs that are not only code-compliant but also materially efficient and cost-effective. The case study involving a G+3 reinforced concrete building showed notable improvements in terms of reduced material usage, cost savings, and structural performance, all achieved through an automated iterative process.

The framework addresses several long-standing challenges in Indian structural design workflows, including fragmented tool usage, manual design iterations, and underutilization of BIM as an analytical platform. By providing a closed-loop system that links design variables to performance metrics via optimization logic, this research transforms BIM from a passive documentation tool into an active decision-making engine. The use of commonly available tools—Revit, Dynamo, and Python—ensures that the solution is accessible to small and mid-sized design firms across India, aligning with the industry's push toward digital transformation.

However, the research also recognizes certain limitations. The scope of optimization was limited to preliminary design parameters, and the model did not incorporate advanced structural behaviors such as dynamic loads, seismic detailing, or reinforcement optimization. These aspects represent valuable opportunities for further development. Moreover, while the study focused on a single case type (RC frame structures), the framework could be extended to other typologies such as steel, precast, or composite systems to assess its scalability and robustness.

Future research should explore the incorporation of multi-objective optimization frameworks that simultaneously consider cost, carbon footprint, and structural performance. The integration of real-time sensor data and Internet of Things (IoT) feedback into the BIM model could also enable adaptive design systems that respond to site conditions or usage patterns. Additionally, automating code compliance checking using IS 456, IS 875, and IS 1893 through rule-based engines would further streamline the workflow. Finally, expanding the framework to support cloud-based collaboration and machine learning-driven optimization would significantly enhance its applicability in large-scale infrastructure projects.

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