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A FRAMEWORK FOR PARAMETRIC BIM IMPLEMENTATION AND DESIGN AUTOMATION IN TRANSPORTATION INFRASTRUCTURE PROJECTS IN INDIA

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ABSTRACT

Transportation infrastructure projects in India are characterised by repetitive components, complex geometries, and multiple design parameters. However, design practices in such projects still rely heavily on two-dimensional drawings and manual three-dimensional modelling, which often lead to increased modelling effort, limited flexibility, and inconsistencies across similar structural elements. The integration of design automation with parametric Building Information Modelling (BIM) provides an approach to improve modelling efficiency, standardisation, and scalability in the design of transportation infrastructure projects. This study presents the implementation of Parametric BIM and design automation in a transportation infrastructure project in India through a case study of a typical bridge structure. A parametric BIM was developed in Autodesk Revit using structural design drawings, where key geometric dimensions was defined to enable flexible modification. Design automation was incorporated using the Dynamo visual programming platform, allowing automated control of parameters and rapid generation of multiple bridge configurations. The results indicate that the automated BIM approach significantly reduces modelling time, improves design adaptability, and enhances data consistency compared to conventional modelling methods. The developed framework also demonstrates scalability, making it suitable for linear infrastructure projects involving repetitive structures.

Keywords: *Building Information Modelling; Design Automation; Dynamo Visual Programming; Parametric Modelling; Transportation Infrastructure.*

1. INTRODUCTION

Transportation infrastructure is a key driver of economic development, regional connectivity, and urban expansion in emerging economies such as India. The country has witnessed significant growth in infrastructure investments through projects such as highways, railway corridors, metro systems, and bridge construction. These projects are inherently complex due to their linear nature, geographical dispersion, repetitive structural elements, and the need for coordinated execution across multiple work fronts.

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Despite the increasing scale and complexity of infrastructure projects, design practices in India still predominantly rely on conventional two-dimensional (2D) drawings and manual three-dimensional (3D) modelling approaches (Rinchen et al., 2024). While 2D drawings serve as an essential communication medium, they often lack the capability to effectively represent spatial relationships and design intent, leading to challenges in visualisation and coordination. Manual 3D modelling enhances visualisation yet can be time-consuming and susceptible to inconsistencies, particularly in projects involving repetitive structural components such as culverts, minor bridges, and retaining structures. These limitations may result in increased modelling effort, reduced flexibility in accommodating design changes, and difficulties in maintaining standardisation across similar infrastructure projects.

BIM has emerged as a transformative digital approach that enables the creation of intelligent and information-rich models integrating geometric and non-geometric data within a collaborative environment (Doan et al., 2025). BIM enhances visualisation, coordination, and design understanding, allowing project stakeholders to identify potential conflicts and improve decision-making during the early design stages of the project (Waqar et al., 2026). Although BIM adoption has gained momentum in vertical construction, its application in transportation infrastructure projects, particularly in combination with design automation, remains relatively limited in the Indian context (Pirdavani et al., 2023).

Design automation, supported by parametric modelling and visual programming tools, provides a promising solution to address the challenges such as repetitive manual modelling tasks, design inconsistencies, coordination errors and time-consuming revisions, across complex infrastructure projects. Parametric modelling allows designers to define relationships between geometric parameters, ensuring that changes in input values automatically update the entire model. Visual programming environments further enable automated workflows and rule-based generation of design alternatives without extensive coding expertise.

However, practical case studies demonstrating the combined implementation of parametric BIM and design automation in Indian infrastructure projects are limited. This research addresses the gap by developing a structured framework for automated BIM, demonstrated through a bridge case study using Autodesk Revit and Dynamo scripts. The framework applies parametric modelling and rule-based automation to enhance modelling efficiency, flexibility, and scalability in transportation infrastructure design.

Therefore, this study aims to develop and demonstrate a structured automated BIM framework integrating parametric modelling and design automation for transportation infrastructure projects in India through a bridge case study using Autodesk Revit and Dynamo. The study further evaluates the effectiveness of the proposed framework in improving visualisation, modelling efficiency, design flexibility, and coordination compared to conventional design practices.

2. LITERATURE REVIEW

The literature review section reviews existing literature on conventional infrastructure design practices, Parametric BIM implementation, parametric modelling, and design automation. It critically examines previous research to identify technological advancements, implementation challenges, and research gaps related to automated BIM workflows in transportation infrastructure projects, particularly within developing country contexts.

2.1 CONVENTIONAL DESIGN PRACTICES IN INFRASTRUCTURE PROJECTS

Design practices in infrastructure projects have traditionally relied on 2D drawings, spreadsheet-based calculations, and experience-driven decision-making. In transportation infrastructure projects such as bridges, culverts, and rail corridors, design information is typically communicated through multiple drawings, including general arrangement drawings, cross-sections, and reinforcement details. Studies indicate that these tools often operate independently, resulting in fragmented information flow and limited coordination between design disciplines (Hartmann et al., 2012). Such fragmented practices can lead to inconsistencies, increased effort in managing revisions, and coordination challenges in repetitive infrastructure components (Lu et al., 2019; Kaur et al., 2025).

2.2 ROLE OF BIM IN INFRASTRUCTURE DESIGN AND VISUALISATION

BIM has emerged as a digital approach that integrates geometric and non-geometric data within a single model, enhancing design visualisation and coordination. Research highlights that BIM improves spatial understanding of complex infrastructure elements and supports multidisciplinary collaboration compared to traditional drawings (Khan et al., 2024). Furthermore, BIM enables early clash detection, improved constructability analysis, and enhanced communication among project stakeholders, thereby reducing design conflicts. Despite these benefits, studies indicate that BIM adoption in transportation infrastructure remains less mature than in vertical construction due to implementation challenges and lack of tailored workflows (Castañeda et al., 2024).

2.3 PARAMETRIC MODELLING IN BIM

Parametric modelling is a key feature of BIM that enables the definition of relationships and constraints among geometric parameters. Researchers have demonstrated that parametric modelling improves design flexibility and consistency while reducing modelling errors (Ding et al., 2014). In infrastructure contexts, this capability is particularly useful for repetitive structural elements, as it supports standardised yet customisable design solutions (Wang et al., 2023). Additionally, parametric BIM provide structured data environments that facilitate downstream integration with scheduling and cost estimation processes (Sacks et al., 2022).

2.4 DESIGN AUTOMATION USING VISUAL PROGRAMMING

Design automation builds upon parametric modelling by enabling rule-based generation of BIM through visual programming tools such as Dynamo and Grasshopper. These tools allow designers to automate repetitive tasks, control geometric parameters, and rapidly generate multiple design alternatives. Studies suggest that automation improves modelling efficiency, minimises human errors, and enhances consistency across similar components (Ding et al., 2014). In linear infrastructure projects, visual programming has been shown to be particularly effective for generating repetitive structural elements along alignments, thereby improving scalability and productivity (Wang et al., 2023). Furthermore, automation facilitates advanced workflows such as generative design and optimisation, expanding the potential applications of BIM in infrastructure projects (Alizadehsalehi et al., 2021).

Although the literature highlights the individual benefits of BIM, parametric modelling, and design automation, their combined implementation in transportation infrastructure remains limited. Existing studies are largely concentrated on vertical construction, with fewer real-world case studies demonstrating automated BIM workflows for infrastructure assets, particularly in developing countries (Khattra et al., 2024). Barriers such as resistance to technological change, lack of skilled professionals, and uncertainty regarding return on investment have further slowed BIM adoption in infrastructure projects (Das et al., 2023). Moreover, there is a lack of structured frameworks illustrating how visual programming can be integrated with parametric BIM to address repetitive infrastructure design challenges.

This research addresses the identified gaps by proposing and implementing a structured framework for automated BIM, demonstrated through a practical bridge case study in India. The framework integrates parametric modelling and design automation to establish a systematic workflow, thereby providing empirical insights into scalable and efficient BIM automation for transportation infrastructure projects.

3. RESEARCH METHODOLOGY

This study adopts an implementation-oriented case study methodology to investigate the integration of automated BIM and design automation in transportation infrastructure projects in India through a Road Under Bridge (RUB) case study. Initially, a comprehensive literature review was conducted to identify research gaps related to BIM implementation, parametric modelling, and automation workflows in infrastructure projects. Based on the identified gaps, the research objectives and framework were formulated. Subsequently, project data were collected and analysed to understand the structural configuration and repetitive components of the selected bridge. Critical geometric and structural parameters were identified and structured into primary and secondary parameters with predefined logical relationships and constraints. Parametric BIM families were then developed in Autodesk Revit for structural components such as box sections and retaining walls by incorporating reference planes, dimensional constraints, and parametric formulas. Following this, Autodesk Dynamo visual programming was integrated with Revit to automate repetitive modelling operations. The developed automation scripts facilitated automatic propagation of parameter changes across interconnected components, thereby reducing manual modelling effort and improving design consistency. Multiple design alternatives were generated by varying predefined input parameters to evaluate modelling flexibility, scalability, and constructability feasibility. Finally, the effectiveness and practical relevance of the proposed automated BIM framework were validated through expert feedback collected from transportation infrastructure professionals using questionnaires and discussions.

4. PROPOSED FRAMEWORK FOR AUTOMATED BIM IMPLEMENTATION

To address the identified gap in structured integration of parametric modelling and design automation within transportation infrastructure projects, this study proposes a systematic automated BIM implementation framework as illustrated in Figure 1.

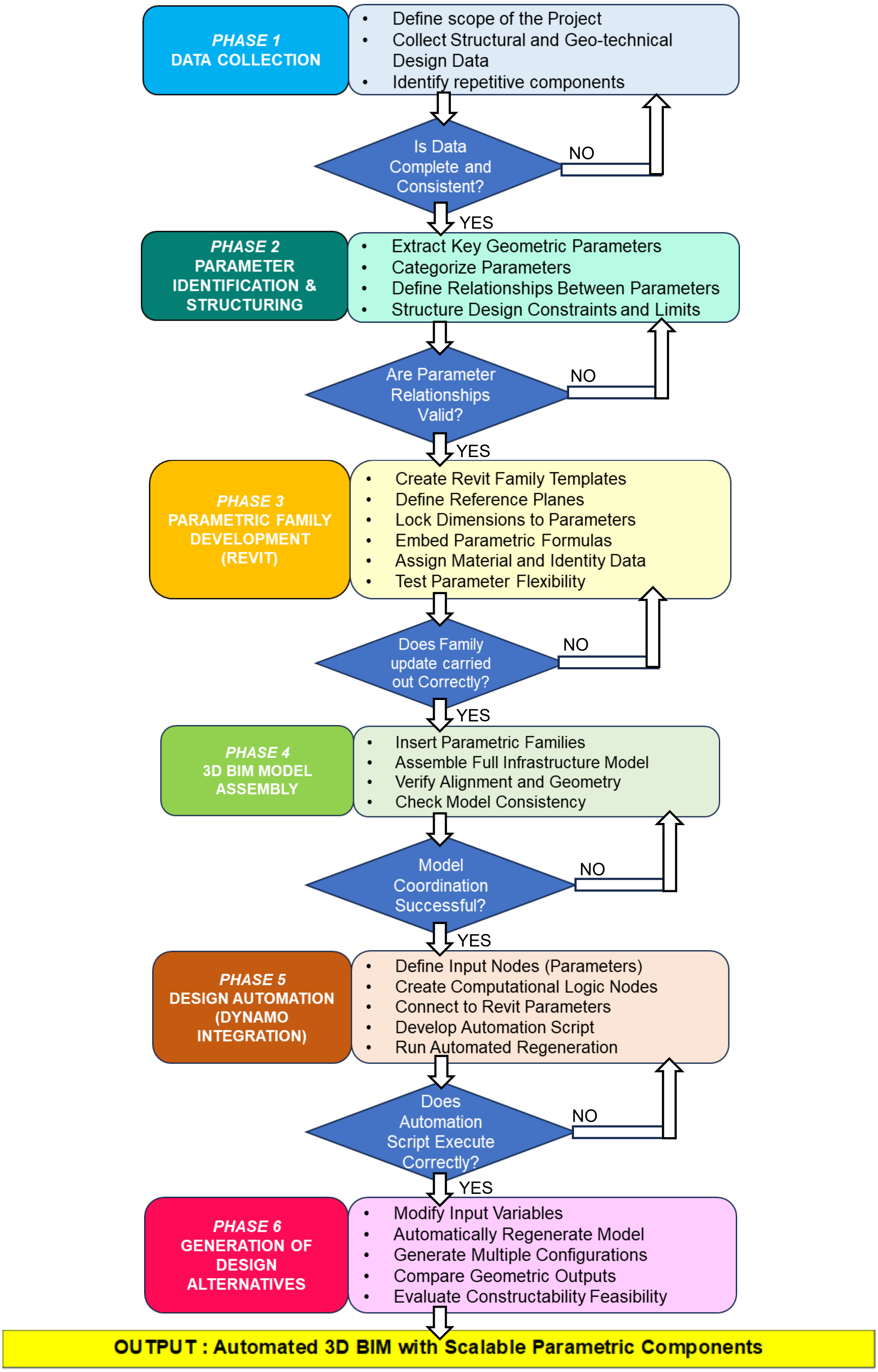

Figure 1: Framework for automated BIM implementation

5. DEVELOPMENT OF BIM PROJECT

After establishing the proposed framework for automated BIM implementation, the following section presents its application within a selected transportation infrastructure case study in India. The framework is utilised to develop an automated BIM project of a RUB minor bridge, demonstrating how structured phases of data preparation, parametric modelling, and automation enable efficient model generation and design flexibility.

5.1 PHASE 1: DATA COLLECTION

The data collection phase establishes the technical foundation for implementing the automated BIM framework. In accordance with the case study methodology adopted in this research, comprehensive design documentation was compiled, including general arrangement drawings, cross-sectional details, structural design calculations, and geo-technical investigation reports. These documents were systematically reviewed to understand the structural configuration, dimensional standards, and alignment characteristics of the selected bridge.

Emphasis was placed on identifying repetitive structural components such as box sections and retaining walls, which are typical in minor bridges in transportation infrastructure projects. Governing dimensions, thickness specifications, material properties, and geometric constraints were extracted and organised for digital translation. Additionally, alignment references and elevation data were examined to ensure spatial accuracy during model development.

This structured and analytical review ensured that the subsequent parametric modelling and automation processes were grounded in validated engineering inputs, thereby, minimising inconsistencies and supporting reliable rule-based model generation.

5.2 PHASE 2: PARAMETER IDENTIFICATION AND STRUCTURING

Following the systematic compilation of design data, the second phase focused on transforming conventional drawing information into structured, controllable modelling parameters. Based on the reviewed structural and general arrangement drawings, critical geometric variables such as span length, box width, deck slab thickness, wall thickness, foundation depth, and vertical clearances were identified. These variables were categorised into primary driving parameters (independent variables controlling overall geometry) and secondary dependent parameters (dimensions governed by predefined relationships).

Hierarchical control logic was established to ensure that modifications to primary parameters would consistently update related geometric elements. Constraint rules and parametric formulas were defined to preserve structural proportions and maintain dimensional integrity. Boundary conditions and permissible design ranges were incorporated to prevent invalid configurations and ensure engineering feasibility.

This structured parameter mapping created a robust computational framework that enabled seamless integration with Revit families and Dynamo automation, forming the core logic for reliable and scalable automated BIM generation.

5.3 PHASE 3: PARAMETRIC FAMILY DEVELOPMENT (REVIT)

In this phase, parametric families were developed in Autodesk Revit to convert extracted parameters into BIM components. Family templates were created for structural elements such as box sections as shown in Figure 2 and retaining walls as shown in Figure 3, incorporating reference planes to control geometric behaviour.

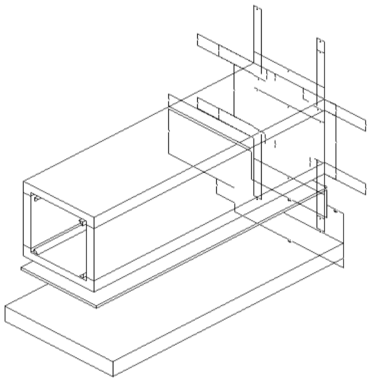

Figure 2: Family – Box section

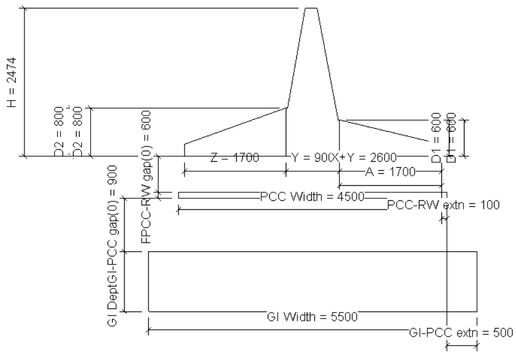

Figure 3: Family – Retaining wall

Critical dimensions were constrained and locked to predefined parameters to enable controlled adaptability. Parametric formulas were embedded to maintain relationships between thickness, height, and span variables, ensuring geometric integrity during modifications. Material properties and identity data were assigned to enrich information content. Flexibility testing was done by varying input parameters to validate model responsiveness, consistency, and compliance with structural design intent.

5.4 PHASE 4: BIM PROJECT CREATION

Following parametric family development, the validated families were instantiated and assembled to generate the complete BIM project of the bridge infrastructure.

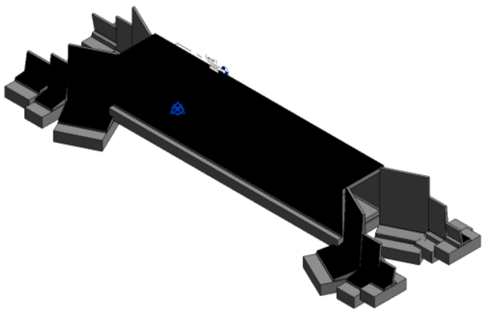

Figure 4: Bridge – 3D view (a)

Figure 5: Bridge – 3D view (b)

Parametric components such as box families and retaining wall families were positioned according to alignment references and structural layout requirements derived from the design drawings. Geometric alignment, connectivity, and dimensional consistency between components were systematically verified. Model coordination checks were conducted to ensure integration accuracy and eliminate spatial conflicts. This phase resulted in a coherent, information-rich BIM project as shown in Figure 4 and 5 ready for automation integration and iterative design modification.

6. DESIGN AUTOMATION

6.1 PHASE 5: DESIGN AUTOMATION (DYNAMO INTEGRATION)

In this phase, design automation was implemented by integrating Autodesk Revit with the Dynamo visual programming environment to enable rule-based control of the parametric BIM. Dynamo scripts were developed to access and manipulate Revit family parameters identified in earlier phases. Input nodes were used to define variable geometric parameters, while computational and logical nodes processed relationships governing component dimensions and spatial configurations. The scripts established a bidirectional data exchange between Dynamo and Revit, ensuring real-time synchronisation between input values and model geometry. Automation logic was designed for the box portion as shown in Figure 6 and the retaining wall portion as shown in Figure 7 to regulate repetitive modelling operations, including dimensional updates and component regeneration, thereby eliminating manual intervention. Any modification to input parameters automatically propagated throughout the interconnected model, preserving consistency across repetitive infrastructure elements.

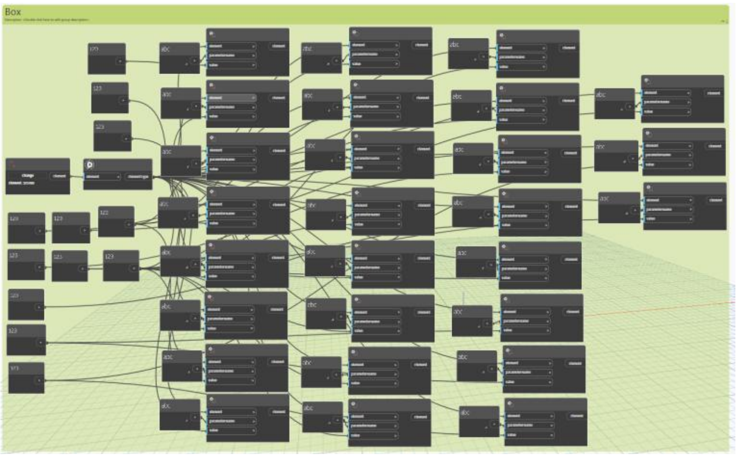

Figure 6: Box section automation code

Figure 7: Retaining wall section automation code

The Dynamo scripts were developed and replicated across multiple components to efficiently generate the complete BIM project as shown in Figure 8.

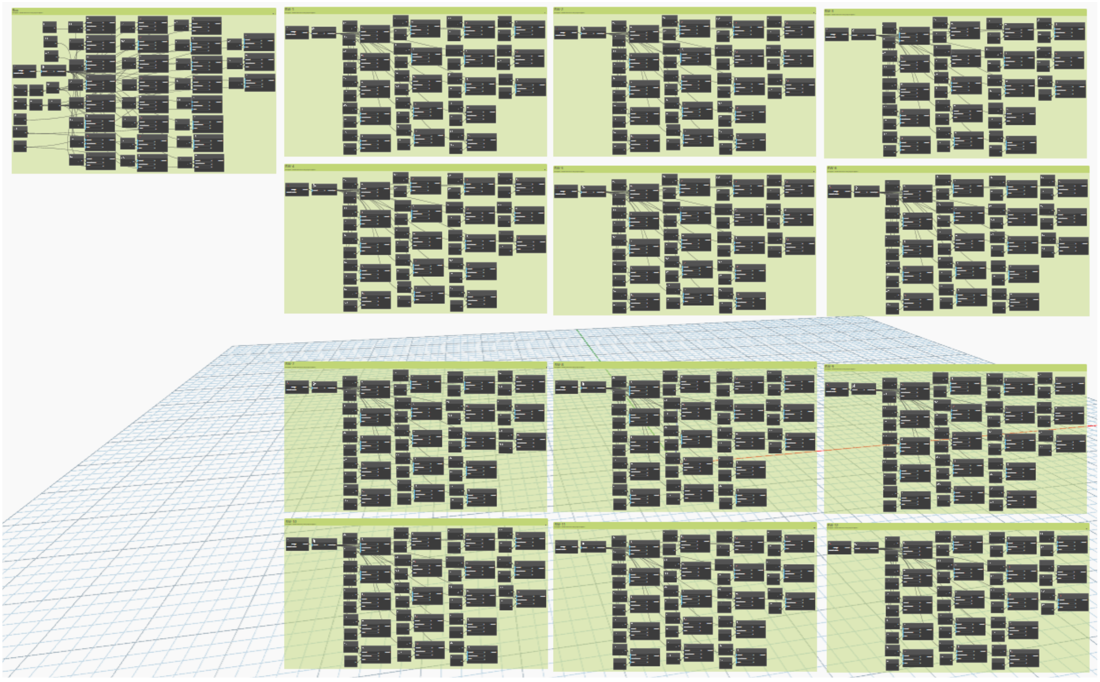

Figure 8: Integrated Dynamo scripts to develop a project

The automation process enabled rapid modification of design parameters and automatic regeneration of the BIM project without manual intervention. The automation workflow involved establishing a connection between Dynamo scripts and Revit parameters. Input nodes were used to define variable parameters, while computational nodes processed these inputs to update geometric relationships within the BIM project. The scripted logic ensured that any change in input parameters automatically propagated throughout the model, maintaining consistency across interconnected components. The workflow demonstrated effective data exchange between Revit and Dynamo, enabling a synchronised and automated modelling environment.

6.2 GENERATION OF DESIGN ALTERNATIVES

In this phase, the developed automation framework was leveraged to systematically generate and evaluate multiple bridge design configurations. By modifying predefined input parameters within the Dynamo interface; such as box section width, box slab thickness, retaining wall height, span length, and alignment offsets - the BIM project was automatically regenerated without manual remodelling. The embedded parametric constraints ensured that all dependent components updated consistently, preserving geometric relationships and structural integrity. This capability enabled rapid iteration of design scenarios to address varying site conditions, clearance requirements, and functional constraints typical of transportation infrastructure projects. Instead of creating separate models for each variation, a single parametric model dynamically responded to input adjustments. The generated alternatives were subsequently assessed for dimensional accuracy, constructability, and scalability across repetitive infrastructure segments. This phase demonstrated the efficiency, flexibility, and decision-support capability of the automated BIM framework in supporting optimised infrastructure design development.

7. RESULTS AND DISCUSSION

The effectiveness of the proposed automated BIM framework was further evaluated through expert feedback obtained from 48 industry professionals involved in transportation infrastructure projects. The proposed framework, along with the developed BIM project, was presented to the professionals, and their opinions were collected to compare conventional project management practices such as the usage of 2D model drawings and disintegrated (or) partially integrated scope-schedule-cost Management with BIM-enabled project workflows. The questionnaire included questions covering key project management aspects such as integration, scope, schedule, cost, quality, resource, risk, procurement, communication, and stakeholder management. Respondents were asked to evaluate the performance of conventional methods and BIM-integrated approaches across these dimensions. The expert opinion survey was conducted to understand the practical relevance, perceived benefits, and implementation challenges of integrating parametric BIM and design automation in transportation infrastructure projects. The insights obtained from the survey support the interpretation of the case study results and provide industry-oriented validation of the proposed workflow.

7.1 IMPROVEMENT IN VISUALISATION AND DESIGN UNDERSTANDING

The results obtained from the expert survey and follow-up interviews indicate that the adoption of automated BIM significantly improves visualisation and design understanding compared to conventional 2D drawing-based practices. Most respondents reported that automated BIM provide clearer spatial representation of infrastructure components, enabling better interpretation of complex structural layouts. The survey results indicated an improvement of approximately 52% in visual reporting and presentation of project information when compared to conventional methods. Experts also highlighted during interviews that automated BIM enhances communication of design intent and facilitates better coordination among multidisciplinary teams, thereby supporting improved decision-making and early identification of potential design conflicts.

7.2 REDUCTION IN MANUAL EFFORT THROUGH DESIGN AUTOMATION

The findings obtained from the expert survey and follow-up interviews indicate that integrating design automation with BIM significantly reduces manual effort associated with repetitive modelling tasks in infrastructure projects. Survey responses showed an improvement of approximately 39% in reducing manual effort in design preparation and planning activities compared to conventional workflows. Experts highlighted during interviews that automation tools such as Dynamo enable rapid generation and modification of repetitive infrastructure components, thereby minimising manual modelling time. In addition to improving efficiency and productivity, respondents noted that automated BIM workflows support sustainability by reducing design rework, optimising resource utilisation, and enabling more efficient planning of infrastructure components.

7.3 IMPROVED DESIGN FLEXIBILITY AND CHANGE MANAGEMENT

Expert survey responses and follow-up interviews indicate that the integration of BIM and design automation enhances design flexibility and supports more effective change management in infrastructure projects. The survey responses showed an improvement of approximately 16% in parameters related to scope clarity and variation management when compared to conventional design approaches. During the interviews, industry professionals emphasised that the parametric nature of BIM enables rapid modification of geometric parameters, allowing changes to automatically propagate across interconnected model components. This capability reduces the need for extensive manual remodelling and facilitates quicker implementation of design revisions, which is particularly beneficial in transportation infrastructure projects where alignment changes and design modifications occur frequently.

7.4 REDUCTION IN ERRORS AND IMPROVED DESIGN CONSISTENCY

Quality-related survey responses indicated reductions in design errors and rework by 24% when using automated BIM. Traditional design workflows often involve manual data transfer between drawings and models, increasing the risk of inconsistencies. In contrast, automated parametric models ensure standardised generation of infrastructure components, improving consistency and reliability of design outputs. This reduction in errors not only enhances design quality yet contributes to improved constructability and reduced downstream rework.

7.5 COMMUNICATION AND COLLABORATION BENEFITS

Another significant outcome of BIM adoption was improved communication and collaboration among project stakeholders. Survey findings showed improvements of approximately 48% in transparency of project information and communication efficiency. The use of automated BIM enables stakeholders to visualise design elements collectively, facilitating multidisciplinary coordination and informed decision-making. This enhanced communication capability is particularly beneficial in infrastructure projects where teams are geographically distributed and require a shared understanding of design information.

7.6 CHALLENGES IN IMPLEMENTING PARAMETRIC BIM AND DESIGN AUTOMATION

Despite the demonstrated benefits, expert opinions identified several challenges associated with implementing parametric BIM and design automation. Limited awareness and uneven technical expertise among stakeholders were highlighted as primary barriers to adoption. Additionally, the development of parametric families and automation scripts requires an initial investment of time and technical skill, which may discourage early implementation. Practical constraints such as limited availability of BIM-enabled hardware and software at site level and resistance to adopting new workflows were also reported as challenges. These findings suggest that successful adoption of BIM automation requires organisational support, training initiatives, and appropriate technological infrastructure.

7.7 DISCUSSION

The findings of the present study demonstrate that integrating parametric BIM with design automation provides measurable improvements over traditional design practices in transportation infrastructure projects. Enhanced visualisation improves design understanding and coordination, while automation significantly reduces manual modelling effort and increases productivity. The parametric nature of automated BIM supports efficient design modifications and ensures consistency across repetitive infrastructure components. However, the gap between awareness and implementation highlights the need for targeted training, standardisation of workflows, and improved technological readiness to support BIM automation adoption.

Overall, the results confirm that parametric BIM and design automation serve as a robust digital foundation for improving infrastructure design processes. By enhancing visualisation, efficiency, and collaboration, automated BIM workflows contribute to more reliable and scalable design practices and provide a pathway for future integration with advanced BIM dimensions and digital project delivery frameworks. Furthermore, the adoption of automated BIM processes can support broader sustainability goals in infrastructure development by enabling optimised resource utilisation, reducing design rework, improving material estimation accuracy, and supporting environmentally responsible planning and decision-making throughout the project lifecycle. These outcomes align with the objectives of Sustainable Development Goal (SDG) 9: Industry, Innovation and Infrastructure, SDG 11: Sustainable Cities and Communities, and SDG 12: Responsible Consumption and Production, which emphasise resilient infrastructure development, sustainable urban planning, and efficient use of resources in construction practices.

8. CONCLUSIONS

This study investigated the implementation of parametric BIM integrated with design automation for transportation infrastructure projects in India through a RUB minor bridge case study. The findings indicate that the combined use of parametric modelling and visual programming significantly enhances design efficiency, visualisation, and consistency compared to traditional design practices. Khan et al. (2024) highlighted that BIM improves collaborative design processes and enhances communication among project stakeholders, which aligns with the improved visualisation and coordination observed in this study.

The integration of automation reduced manual modelling effort and enabled rapid generation of repetitive infrastructure components. This finding and the ability of the automated 3D model is consistent with Ding et al. (2014), who demonstrated that parametric BIM enhances modelling efficiency, and with Wang et al. (2023), who reported that automation improves scalability and consistency in linear infrastructure projects.

Despite these advantages, the study has certain limitations. The research focused on a single infrastructure case study, which may limit the generalisability of the results across other infrastructure asset types. Additionally, the automation framework primarily addressed geometric modelling pertaining to the design and planning phase of the project. These limitations reflect the challenges identified by Khattra et al. (2024) and Das et al. (2023), who reported that BIM adoption in infrastructure projects is constrained by skill gaps, technological barriers, and organisational readiness across different phases of the project.

Future research should extend automated BIM workflows toward integration with scheduling, cost management, and real-time monitoring systems. Integrating automation with advanced technologies such as generative design and digital twins can further improve infrastructure lifecycle performance. These developments can also support sustainable infrastructure planning by optimising resource utilisation, minimising design rework, and contributing to SDG 9, SDG 11, and SDG 12, which promote resilient infrastructure and responsible resource use.

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