DFMA (Design for Manufacture & Assembly) Technologies in Indian Construction

Barriers, Drivers, and Workflow Implications

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Introduction: The RCC Challenge & DfMA Opportunity

RCC Dominance in India

The Indian construction industry relies predominantly on conventional cast-in-situ reinforced cement concrete (RCC) methods, which are increasingly challenged by systemic inefficiencies.

- **Time overruns** due to sequential workflows and dependency on site execution
- **Labour dependency** with inconsistent skill levels affecting quality and productivity
- **Quality variability** arising from workmanship and supervision inconsistencies
- **Inefficient coordination** among stakeholders leading to rework and delays

These challenges become more pronounced as projects grow in scale and complexity, placing greater pressure on contractors to deliver faster, safer, and more predictable outcomes.

DfMA: A Global Solution

Design for Manufacture and Assembly (DfMA) integrates design decisions with manufacturing and assembly processes to enable efficient off-site production and streamlined on-site installation.

- **Improved productivity** through controlled factory environments and parallel workflows
- **Enhanced quality** via standardized components and reduced on-site variability
- **Reduced uncertainty** through early design finalization and integrated coordination
- **Faster delivery** by relocating labor-intensive activities to factory settings

The Indian Context

Despite demonstrated global benefits, DfMA adoption in India remains limited and fragmented, constrained by ecosystem readiness rather than technological availability.

Literature Review: RCC Limitations & DfMA Concepts

RCC limitations → DfMA principles → Global and Indian adoption → TOE barriers → Synthesis → Research gap.

01 RCC Workflow Characteristics

Cast-in-situ RCC workflows are organized around a site-first logic where design execution, material placement, reinforcement fixing, formwork erection, and concreting occur sequentially on site.

- **Site-centric execution:** Linear sequence constrains parallelization
- **High labour intensity:** Skilled trades required in large numbers
- **Fragmented coordination:** Ad hoc, project-specific collaboration

02 Key Limitations

Extended Duration
Sequential activities make timelines sensitive to disruptions

Quality Variability
Depends heavily on workmanship and supervision

Material Inefficiency
Wastage from cutting losses and rework

Coordination Gaps
Design decisions finalized during execution

03 DfMA Core Principles

DfMA represents a fundamental shift where design decisions are explicitly aligned with manufacturing and assembly processes, emphasizing standardization, repeatability, and early integration.

- **Standardization** of components for factory production
- **Early design finalization** to enable manufacturing planning
- **Simplified connections** for efficient on-site assembly
- **Parallel workflows** with off-site and on-site activities

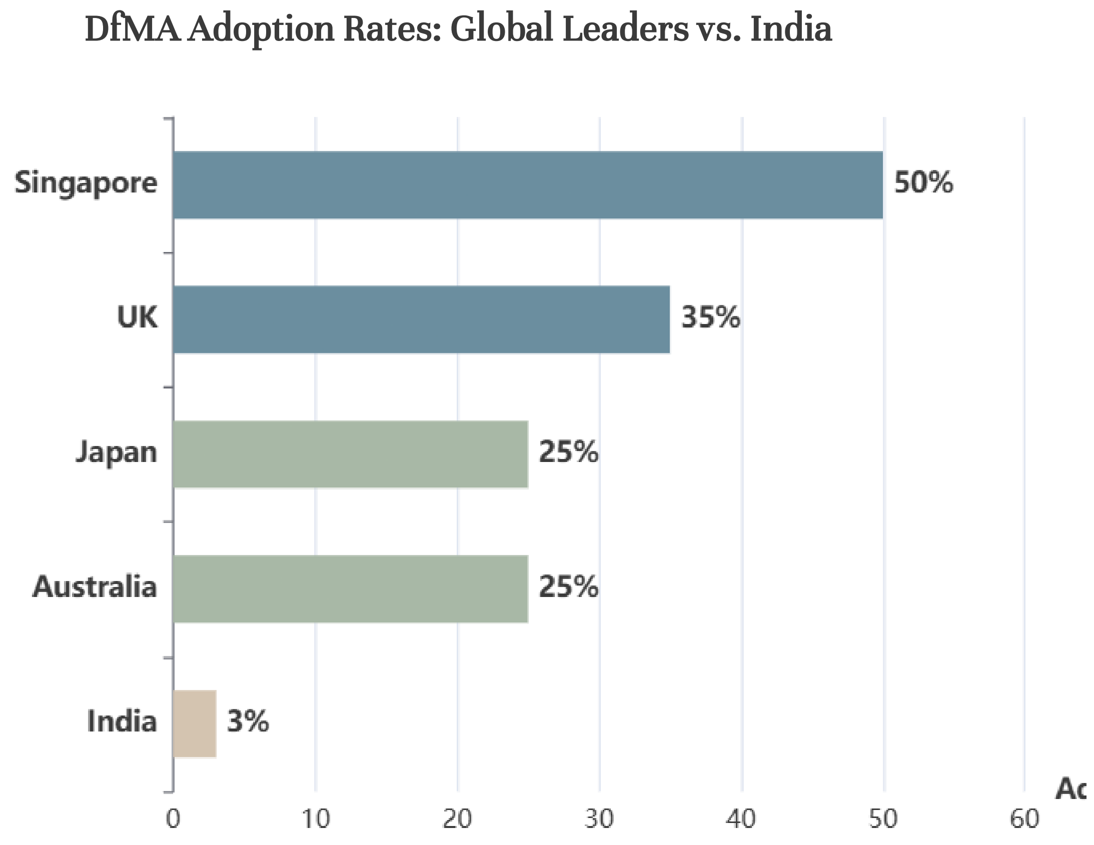
04 DfMA Systems & Applications

- Precast concrete systems
- Modular construction
- Light-gauge steel framing
- Prefabricated service pods
- Volumetric units
- Hybrid precast-in-situ

Digital Enablement: BIM serves as a critical enabler, supporting clash-free coordination, fabrication-ready data generation, and integrated scheduling linking off-site production with on-site assembly.

Global vs. Indian Context: The Adoption Gap

Comparative analysis using the TOE framework reveals structural barriers beyond technological feasibility



Global Leaders

Singapore (50%): Policy mandates, high BIM maturity

UK (35%): Government-backed programs, standards

Japan (25%): Long-standing manufacturing integration

Australia (25%): Market response to labour challenges

India (3%)

Technology: BIM Level 1 only, manual coordination

Organisation: Siloed teams, RCC expertise only

Environment: Fragmented supply chains, cheap labour

Policy: Limited to PMAY pilot projects (<1%)

Key Insight: India's DfMA adoption lags due to technological immaturity, organizational silos, and economic conditions favoring conventional RCC construction (₹800/day labour).

Research Objectives & Questions

Main Research Question

How can Design for Manufacture and Assembly (DfMA)-enabled project delivery be effectively adopted within the Indian construction industry through organisational workflow transformation and readiness development?

01 Objective 1

Examine RCC limitations and analyse TOE factors affecting DfMA adoption in India, including comparison with global drivers.

RQ1.1
What operational limitations are associated with conventional RCC?

RQ1.2
Why have global adoption drivers not translated effectively into India?

RQ1.3
What TOE barriers constrain DfMA adoption in India?

02 Objective 2

Investigate workflow transformation required for DfMA adoption, analysing differences between conventional and DfMA-enabled delivery.

RQ2.1
How do workflows differ between RCC and DfMA delivery?

RQ2.2
What organisational challenges arise during transition?

RQ2.3
What role do digital tools like BIM play in enabling transition?

03 Objective 3

Develop a DfMA adoption readiness and transition framework tailored to Indian construction organisations.

RQ3.1
What organisational capabilities are required for successful adoption?

RQ3.2
How can barriers and transformation requirements be integrated into a framework?

Outcome: Practical framework for assessing readiness and guiding transition

Limitations of Conventional RCC Construction → **Conditions Where DfMA Provides Advantages** → **Barriers to DfMA Adoption in India (TOE Framework**

Workflow difference → **Transition challenge** → **Perception and digital support.**

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Conceptual Framework: TOE + Workflow Transformation

Integrating the Technology-Organization-Environment framework with organizational readiness and workflow shift

Technological Factors

- BIM maturity and digital tools
- Design-manufacturing interoperability
- Standardization capability
- Off-site construction technologies
- Logistics and transportation

Organizational Factors

- Top management commitment
- Workforce skills (BIM & DfMA)
- Early collaboration practices
- Prior off-site experience
- Resistance to change

Environmental Factors

- Government policies and mandates
- Supply chain maturity
- Labour market conditions
- Client procurement practices
- Market demand for speed

Conceptual Framework for DfMA Adoption

Technological | Organizational | Environmental

↓

Organizational Readiness

Capability development · Leadership alignment · Process integration

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Workflow Transformation

Sequential RCC (Site-centric) → Integrated DfMA (Manufacturing-led)

↓

DfMA Adoption Outcomes

Time reduction · Quality enhancement · Material efficiency

Methodology: Mixed-Methods Approach

Exploratory research design combining quantitative surveys and qualitative interviews

01 Research Philosophy

Interpretivist approach recognizing that DfMA adoption is influenced by stakeholder perceptions and organizational practices.

Different stakeholders interpret DfMA differently:

- Architects view early design finalization as restrictive
- Contractors prioritize labour-based methods
- Decision-makers perceive high initial investment as risk

02 Research Design

Exploratory mixed-methods design due to limited DfMA adoption in India and lack of empirical workflow-based studies.

Quantitative
Questionnaire survey for trends and patterns

Qualitative
Interviews for contextual understanding

03 Research Approach

Abductive approach involving continuous interaction between theory and data. Concepts from literature guided survey design, field data was analyzed, and findings refined the theoretical framework.

04 Data Sources

Primary Data

- Questionnaire survey (24 professionals)
- Semi-structured interviews (face-to-face & telephonic)

Secondary Data

- Academic literature on DfMA and off-site construction
- Industry reports and policy documents

05 Sampling Strategy

Purposive sampling to ensure respondents possessed relevant knowledge and experience in construction workflows and prefabrication.

Contractors	Architects	PM/BIM
~10-15	~5-10	~5-10

06 Data Analysis

Quantitative
Mean score analysis, ranking, frequency distribution

Qualitative
Thematic analysis with coding and theme development

Data Collection: Survey & Interview Insights

Mixed-method data collection ensuring triangulation and comprehensive understanding

Questionnaire Design

Six-section questionnaire designed based on literature review findings, research gaps, and TOE framework dimensions.

Section A	Respondent profile and background
Section B	RCC practices and current issues
Section C	Workflow transformation comparison
Section D	Organizational readiness factors
Section E	Digital and policy factors (BIM)
Section F	Framework validation feedback

Interview Method

Semi-structured interviews conducted to complement survey data and provide qualitative depth:

Purpose
Validate survey findings, understand real-world workflows, identify practical challenges

Format
30-45 minutes duration, face-to-face and telephonic modes, flexible questioning

Key Areas
RCC workflows, DfMA perceptions, readiness gaps, BIM role, framework feedback

Respondent Profile

Sample Size
24 valid responses from construction professionals

Professional Roles
Designers (25%), Contractors/PMs (20.8%), BIM professionals, Site engineers

Project Types
Commercial (66.7%), Residential (58.3%), Industrial (37.5%), Infrastructure (29.2%)

Stage Involvement
Design (54.2%), Site execution (41.7%), Planning (33.3%)

DfMA Awareness
100% awareness, mixed prefabrication experience

Quality Assurance

- **Pilot testing** conducted for questionnaire clarity
- **Content validity** ensured through literature alignment
- **Triangulation** via multiple data sources (survey + interviews + literature)
- **Ethical considerations**: Informed consent, confidentiality, data security

Data Analysis: Key Findings on Barriers & Drivers

Organizational factors emerge as the most critical barriers to DfMA adoption in India

RCC Construction Challenges

Frequency of Delays
Mean: 4.46

Very High – Systemic inefficiencies in traditional workflows

Design Changes
87.5%

Ranked as most significant challenge – Late changes cause rework

Poor Coordination
70.8%

Coordination failures and fragmented workflows

Rework Issues
75%

High rework levels from clash detection during construction

DfMA Requirements

Early Design Finalization
Mean: 4.3

Very High importance – Critical requirement for DfMA

Coordination Level
Mean: 4.2-4.5

High to Very High – Significantly higher than RCC

Critical Stage
75%

Design stage identified as most critical in DfMA

TOE Readiness Assessment

Technological Gap (Moderate)
Limited BIM integration and digital capability. BIM used for basic 3D modeling only, not manufacturing-level detailing.

Organizational Gap (Most Critical)
Poor coordination, resistance to change, lack of structured workflows, limited skills. **This is the primary barrier.**

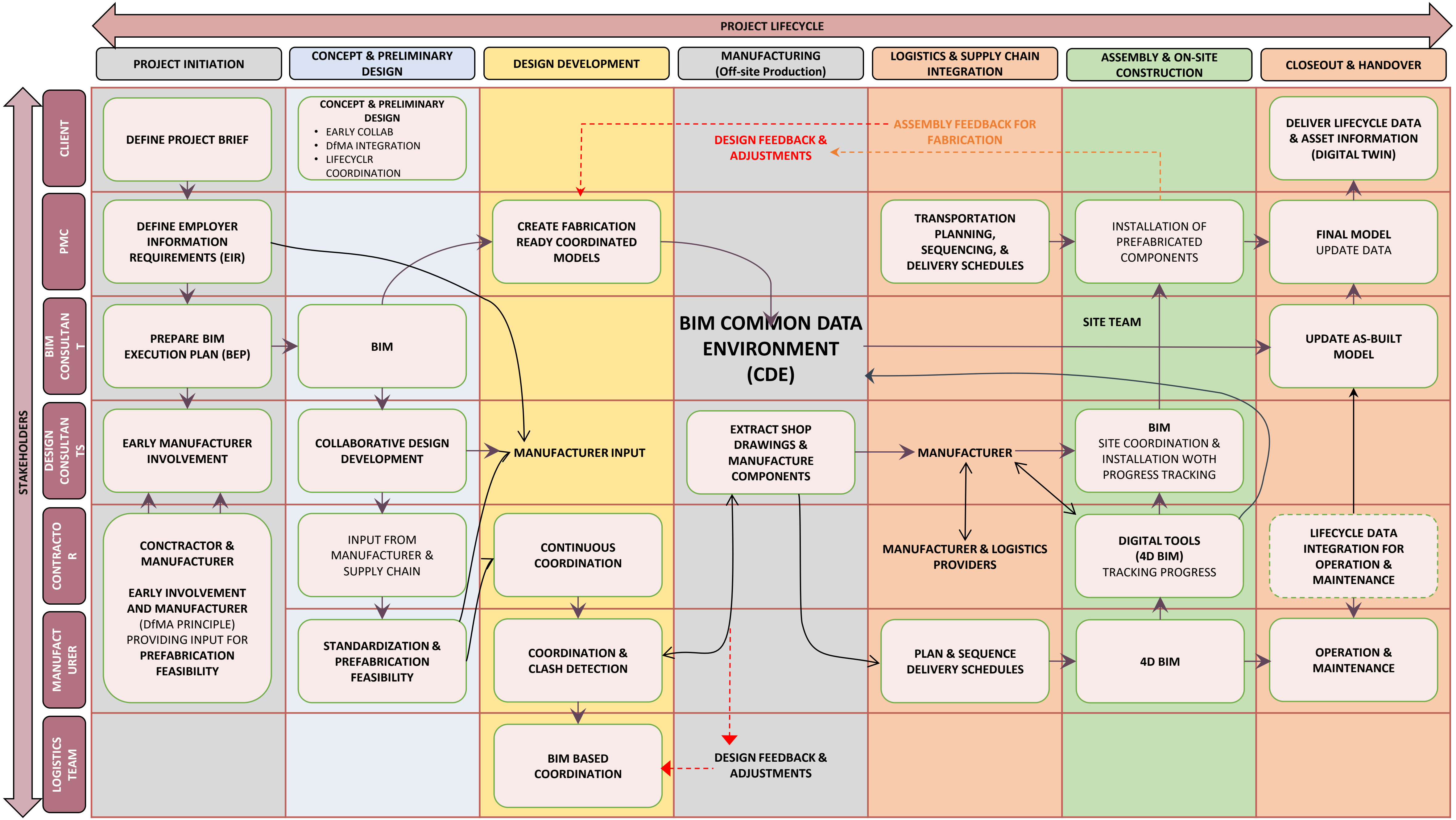
Environmental Gap (Moderate to High)
Weak policy support, fragmented supply chains, economic conditions favoring labour-intensive methods.

Key Organizational Factors

Coordination mechanisms	95.8%
BIM/digital capability	91.7%
Supply chain readiness	87.5%
Skilled workforce & leadership	75%

Framework Validation: 91.7% agreed that a structured readiness framework would support organizations in adopting DfMA effectively.

Workflow Transformation



Workflow Comparison: RCC vs. DfMA

Fundamental shift from sequential site-centric processes to integrated manufacturing-led delivery

Conventional RCC Workflow

Process Characteristics

- Linear and stage-based progression
- Design stages completed in isolation
- Coordination occurs at later stages
- Construction begins before full design resolution
- Issues resolved on-site through rework

Key Limitations

- **Fragmentation:** Consultants operate independently
- **Sequential dependency:** Activities dependent on approvals
- **Late clash detection:** Conflicts identified at advanced stages
- **Repetitive approvals:** Frequent feedback loops
- **Delayed contractor involvement:** Limited constructability input

Outcomes

- Extended timelines
- Cost overruns
- High rework
- Reduced productivity

DfMA-Enabled Workflow

Process Characteristics

- Early integration of all stakeholders
- Manufacturers involved from project initiation
- BIM-enabled coordinated design development
- Continuous feedback between design and manufacturing
- Shift from site construction to off-site fabrication

Key Innovations

- **Early collaboration:** All stakeholders from concept stage
- **Design for manufacturing:** Production constraints embedded early
- **Clash-free coordination:** Issues resolved before construction
- **Parallel workflows:** Off-site and on-site activities simultaneous
- **Just-in-time logistics:** Aligned delivery and assembly

Outcomes

- Time efficiency
- Improved quality
- Reduced rework
- Enhanced productivity

RCC
Sequential · Reactive · Site-dependent

→

DfMA
Integrated · Proactive · Manufacturing-led

DfMA Adoption Transition Framework

Four-stage structured approach for transitioning from site-centric to manufacturing-led construction

01 Readiness Assessment

Evaluate current capabilities

- **Technological:** BIM maturity, digital tools assessment
- **Organizational:** Coordination practices, skill levels
- **Environmental:** External support, supply chain conditions

Objective: Identify specific readiness gaps before implementation

02 Strategic Planning

Develop transition strategy

- **System selection:** Precast, modular, or hybrid DfMA
- **Delivery approach:** Define project delivery model
- **Stakeholder alignment:** Early collaboration framework

Objective: Align project objectives with DfMA requirements

03 Implementation & Integration

Operationalize DfMA

- **BIM-enabled coordination:** Clash-free design development
- **Early design finalization:** Freeze design for manufacturing
- **Manufacturing integration:** Link design to production
- **Logistics alignment:** Just-in-time delivery planning

Objective: Shift from sequential to parallel integrated processes

04 Monitoring & Improvement

Evaluate and refine

- **Performance metrics:** Track time, cost, quality outcomes
- **Stakeholder feedback:** Capture lessons learned
- **Continuous optimization:** Refine processes and skills

Objective: Ensure long-term sustainability of DfMA adoption

Gap-Strategy Alignment

Technological Gaps
→ BIM integration & digital capability development

Organizational Gaps
→ Coordination restructuring, training, leadership commitment

Environmental Gaps
→ Supply chain strengthening & policy alignment

Conclusion & Research Contributions

Theoretical Contribution

Applied the TOE framework to synthesize DfMA adoption barriers specific to India, demonstrating that organizational factors (coordination, skills, resistance) constitute the primary constraints rather than technological limitations.

Empirical Contribution

Compared conventional and DfMA workflows through mixed-methods analysis, documenting practitioner perceptions and revealing that workflow transformation requires shifting from sequential site-centric to integrated manufacturing-led processes.

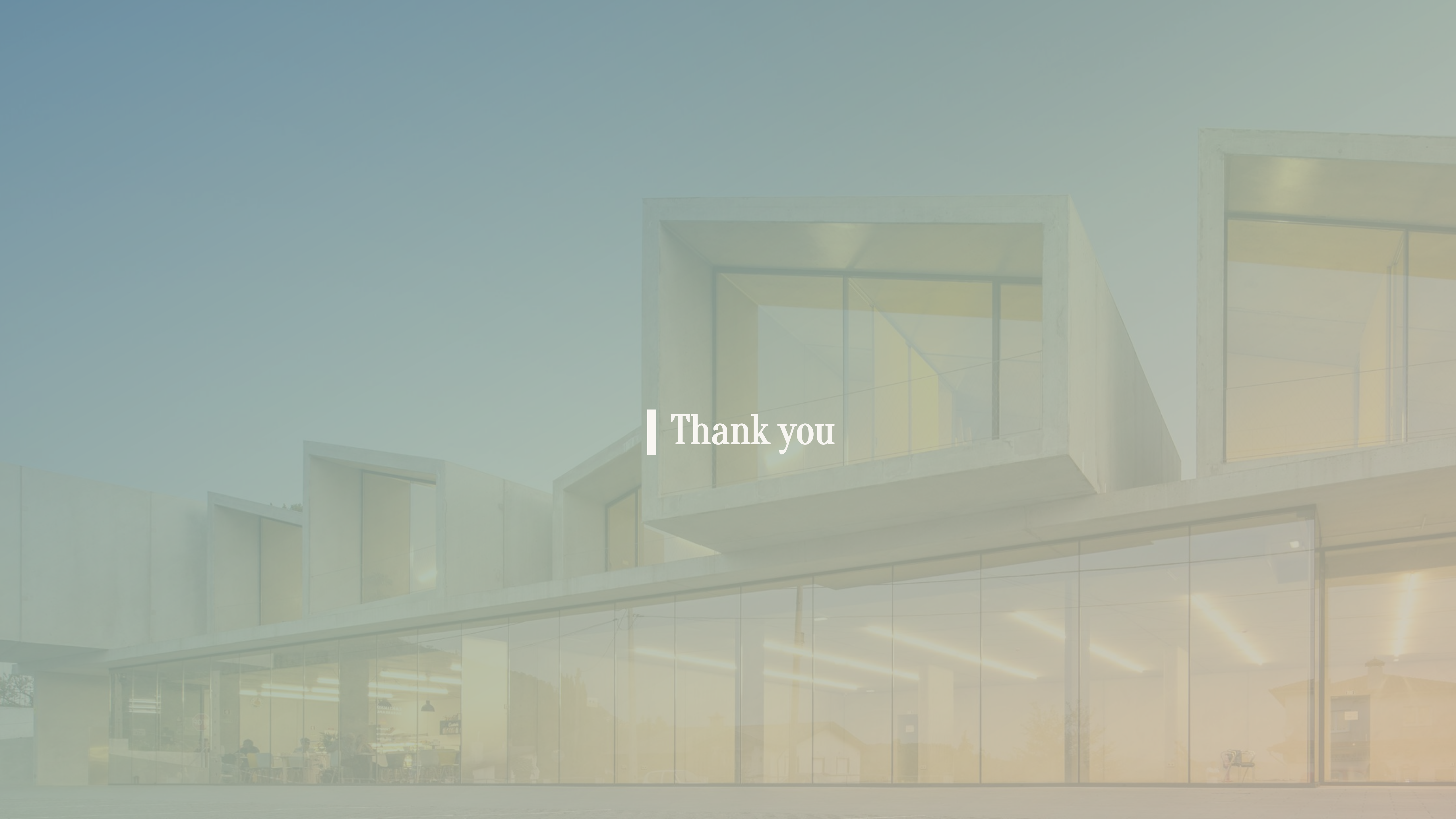
Practical Contribution

Developed a four-stage DfMA adoption transition framework tailored to Indian construction, providing organizations with a structured roadmap for assessing readiness and guiding the transition to manufacturing-led project delivery.

Key Findings Summary

- **RCC challenges are systemic:** High delays (Mean = 4.46), frequent design changes (87.5%), poor coordination (70.8%)
- **DfMA requires fundamental shift:** Early design finalization (Mean = 4.3), integrated coordination, manufacturing-led execution
- **Organizational gap is most critical:** Poor coordination, resistance to change, limited skills, lack of leadership commitment
- **Adoption requires systemic alignment:** Technology + Organization + Environment must be addressed holistically

This study confirms that DfMA adoption in India is primarily an organizational and workflow transformation challenge rather than purely technological, requiring systemic alignment of coordination practices, digital capability, and leadership commitment to enable the transition from labour-intensive site-centric construction to industrialized manufacturing-led project delivery.



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