DIRECTED RESEARCH PROJECT

Barriers to the Adoption of 3D Concrete Printing in Indian Construction Industry

Researcher: Tanmay Desai (PCM24414)

Program: Master of Technology - Construction Engineering & Management

Institution: CEPT University, Faculty of Technology

Guides: Sh. Siddharth Panjwani & Dr. Amarnath CB

Spring 2026

Research Overview

01 Introduction & Research Context

3DCP potential, adoption gap in India, research objectives and questions

02 Literature Review

Five barrier categories: Technical, Economic, Regulatory, Social, Environmental

03 Research Methodology

Mixed-methods approach: literature review, qualitative interviews, framework development

04 Data Collection & Analysis

Phase 1: 29 barriers identified I Phase 2: Barrier validation through stakeholder interviews

05 Framework Development

4-dimensional readiness framework with scoring system and stakeholder mapping

06 Key Contributions & References

Framework contributions and complete reference list from the research

01 Introduction: The 3DCP Challenge in India

The Problem Context

India's Construction Sector: Employs 50 million workers, facing projected shortage of 20 million skilled labourers by 2030

3DCP Global Success: Demonstrated technical feasibility in Europe, China, Middle East with 30-60% faster construction, 20-35% waste reduction, 15-20% labour savings

India's Adoption Gap: Adoption remains below 1%, confined to pilot projects with cost premiums and unverified durability

Research Aim & Objectives

Aim: To identify, analyze, and classify key technical, economic, organizational, and regulatory barriers affecting 3DCP adoption in Indian construction industry

5	29	4
Barrier Categories	Barriers Identified	Readiness Dimensions

Research Questions

Q How do interconnected technical, economic, regulatory, social, and environmental barriers impede 3DCP adoption?

Specific sub-questions:

- Material, standardization & QC challenges?
- Cost, ROI & supply chain gaps?
- Building codes & certification hurdles?
- Workforce resistance & skills gaps?

Research Scope

In Scope

Indian & international case studies, technical/organizational barriers, cost perceptions, expert interviews

Out of Scope

Structural calculations, developing new printing systems, on-site prototype printing

02 Literature Review: Five Barrier Categories

Technical / Technological

- Interlayer bonding strength variability
- Rheology, viscosity & pumpability control
- Buildability & geometric stability
- Reinforcement integration challenges
- Printer-process integration gaps

Economic / Business Model

- High capital expenditure (CapEx)
- ROI uncertainty & payback ambiguity
- Low equipment utilisation rates
- Market demand unpredictability
- Limited financing & insurance products

Environmental / Sustainability

- Site logistics & infrastructure constraints
- Circularity & end-of-life uncertainty
- Absence of green-tender incentives
- Limited LCA data for 3DCP

Administrative / Regulatory

- Absence of BIS/IS standards for 3DCP
- Fragmented code interpretation
- Municipal approval uncertainty
- Public procurement misalignment (L1 tendering)
- Project-specific material validation

Social / Organisational

- 3DCP-ready skills shortage
- Perceived labour displacement risk
- Health & safety compliance gaps
- Resistance to change within firms
- Knowledge & communication gaps

Research Gap

While individual studies examine subsets of barriers, **limited empirical validation exists within Indian contractor ecosystem**, particularly from Tier-1 firms and developers.

This study advances literature by:

1. Structuring 29 barriers across 5 categories
2. Validating barriers through stakeholder interviews
3. Developing contextual framework for adoption

03 Research Methodology: Mixed-Methods Approach

Research Methodology Flowchart

Phase 1
Systematic Literature Review

→

Phase 2
Research Questions & Scope

↓

Phase 3: Empirical Research
- Phase 1: General Questions
- Phase 2: Specific Questions

→

Phase 4
Framework Scope Development

↓

Phase 5: Framework Development
Barriers & Readiness Assessment Framework

5	8+	29
Sequential Phases	Stakeholders Interviewed	Barriers Identified

Participant Selection

- **Contractors:** 5+ years experience, tech adoption exposure
- **Structural Consultants:** 3+ years, innovative systems
- **Developers:** Decision-makers, mass housing exp.
- **Technology Providers:** 3DCP vendors, material firms
- **Architects:** DFMA workflows, advanced geometry
- **Government:** Code development, BIS committees

Interview Protocol

- **Duration:** 45-60 minutes
- **Format:** Semi-structured (Google Meet/In-person)
- **Approach:** Open-ended, experience-based
- **Recording:** Transcribed & anonymized

Tools & Techniques

- Google Meet, Otter
- Scholar, SpringerLink
- Excel, Miro, SPSS
- Word / LaTeX

04 Data Collection: Phase 1 - Identifying 29 Barriers

Phase 1: Barriers Results - Mind Map Overview

Technological
- Printer-Process Integration
- BIM Interoperability

2

Technical
- Rheology Control
- Interlayer Bond
- Buildability
- Durability
- Reinforcement
- QC Standards

6

Economic
- High Capital Cost
- Material Premium
- Productivity Risk
- Market Demand

4

Business Model
- Finance Access
- Uncertain ROI

2

Regulatory
- No BIS Standards
- Code Fragmentation
- Approval Uncertainty
- Procurement Gap
- Material Approval

5

Social
- Skills Shortage
- Labour Displacement
- Safety Gaps
- Insurance Gap

4

Environmental
- Site Logistics
- Circularity Unclear
- No Green Incentives

3

Organizational
- Readiness Gaps
- Knowledge Gaps
- Resistance to Change

3

Method: Thematic analysis of 8 semi-structured interviews with industry professionals

29
Total Barriers

Phase 1 Approach

General Exploratory Questions
20 open-ended questions covering all barrier categories (see Annexure 1)

Stakeholder Diversity
Contractors, consultants, developers, tech providers, architects

Data Analysis
Systematic coding & thematic analysis to identify preliminary factors

→ To Phase 2

These 29 barriers formed the foundation for **Phase 2 specific questions**, enabling deeper validation and refinement through targeted stakeholder interviews.

04 Data Collection: Phase 2 - Barrier Validation

Three-Stage Analytical Chain

1 Interview Statement
Raw qualitative input from stakeholders capturing lived experiences

↓

2 Code (Condensed)
Key ideas extracted as keywords or short phrases

↓

3 Barrier Mapping
Alignment with final barrier categories and specific indicators

Validation Outcome

Each barrier in the final framework is **traceable to actual industry insights**, ensuring empirical grounding and practical relevance.

Stakeholder Examples

Architect
"Printed elements are designed as hollow sections... reinforcement is not embedded like traditional RCC..."

Non-conventional structural behavior | Lack of embedded reinforcement

→ **Technical Barrier:** Reinforcement & Load-Path Detailing

Developer
"Even if technically viable, developers prioritize cost efficiency... financial justification is lacking..."

Cost-driven decisions | Weak ROI

→ **Economic Barrier:** Market Demand & Revenue Uncertainty

Contractor
"If the mix is slightly off or the print pauses, the whole element can fail... cost, delay, and liability issue..."

Process sensitivity | Execution risk

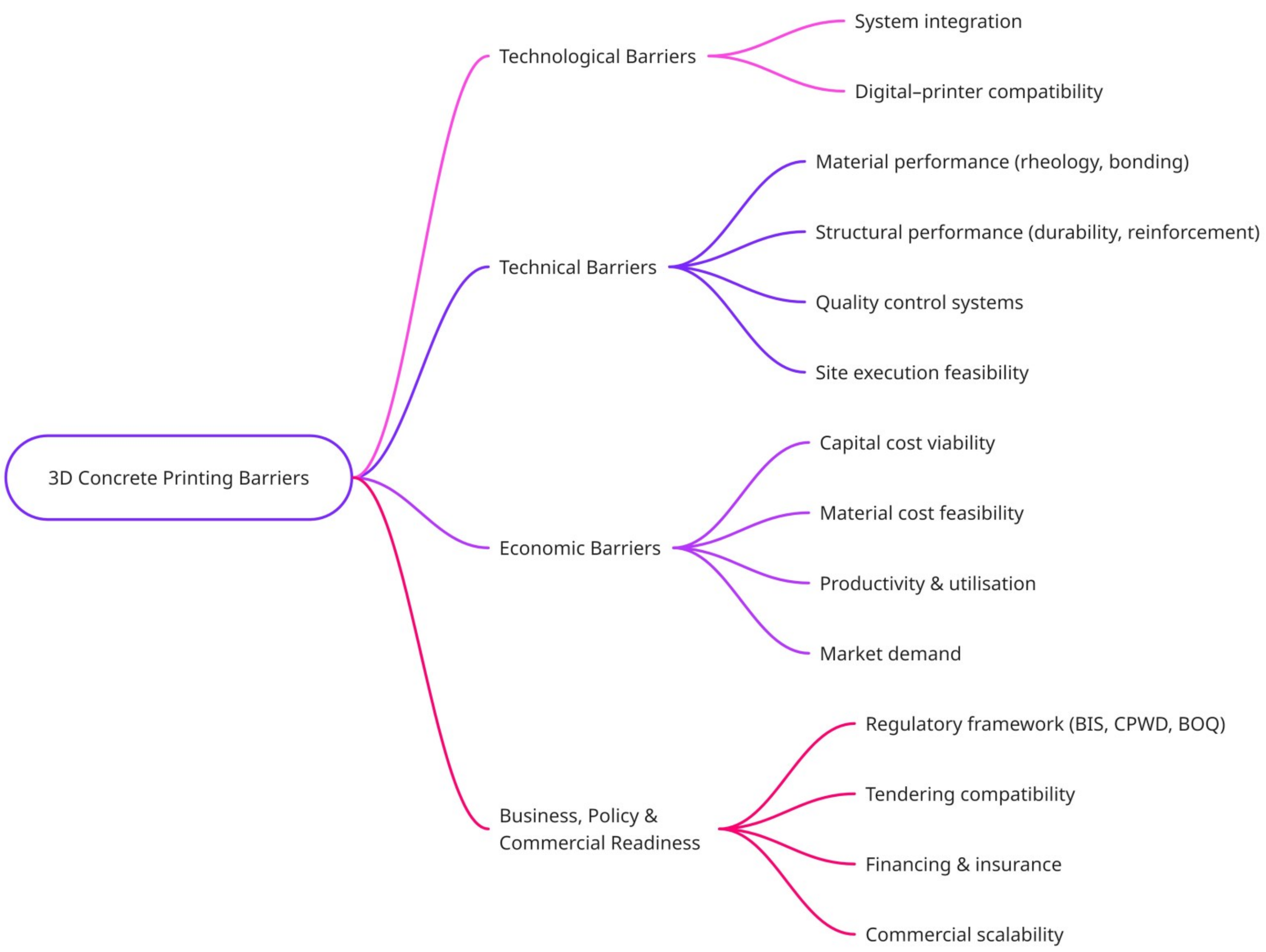
→ **Economic Barrier:** Productivity & Utilisation Risk

Academician
"The technology is design-driven, not demand-driven... without demand, policies don't develop..."

Demand-side weakness | Supply-driven innovation

→ **Economic + Regulatory Barriers**

04 Data Collection: Phase 2 - Barriers



05 Framework Architecture: Four Readiness Dimensions

Framework Name

"Stakeholder-Driven, Barrier-Driven 3DCP Adoption Readiness Framework for Indian Construction Industry"

Four Readiness Dimensions

Technological Readiness

Digital & machine integration

- Printer-process integration
- BIM interoperability
- Workflow standardization

Technical & Constructability

Engineering & site feasibility

- Material rheology control
- Interlayer bond strength
- Quality control frameworks

Economic Readiness

Cost & financial viability

- Capital cost viability
- Productivity efficiency
- Market demand strength

Business, Policy & Commercial

External support environment

- Regulatory framework
- Tender integration
- Insurance coverage

Core Objective

To assess the readiness of the Indian construction ecosystem for adopting 3DCP by evaluating multi-dimensional barriers and identifying stakeholder-specific responsibilities.

Seven Stakeholder Groups

- G **Government/Regulators** - Sets rules & standards
- D **Developers/Clients** - Creates demand
- C **Contractors** - Executes the work
- T **3DCP Technology Firms** - Provides tech & support
- A **Architects/Designers** - Shapes digital design
- E **Structural Engineers** - Confirms safety
- F **Financial Institutions** - Supports funding

Core Hypothesis

"Adoption of 3D Concrete Printing is governed by the **weakest readiness dimension**, and each dimension is influenced by specific stakeholders."

05 Indicator Development & Scoring System

Indicator Framework

Technological (4)
Integration, Workflow, Interoperability, Proprietary

Technical (7)
Rheology, Bond, Reliability, Durability, QC, Site, Skills

Economic (6)
Capital, Material, Productivity, Utilisation, Demand, Revenue

Business/Policy (7)
Regulatory, Tender, Approval, Finance, Insurance, Scalability, Contracts

14
Total Indicators

Scoring Formula :- Overall Readiness Score

$$ORS = (D_1 \times W_1) + (D_2 \times W_2) + (D_3 \times W_3) + (D_4 \times W_4)$$

Where: $W_1+W_2+W_3+W_4 = 1.0$

D_1 = Technological	$W_1 = 0.10\text{-}0.15$
D_2 = Technical	$W_2 = 0.20\text{-}0.25$
D_3 = Economic	$W_3 = 0.30\text{-}0.35$
D_4 = Business/Policy	$W_4 = 0.25\text{-}0.30$

5-Point Readiness Scale

1	2	3	4	5
Not Ready	Low	Moderate	High	Fully Ready
Absent/weak	Fragmented	Partial	Largely ready	Standardized

Readiness Interpretation Bands

1.0 - 2.0
Not Suitable
Major barriers unresolved

2.1 - 3.0
Pilot Stage
Controlled trials only

3.1 - 4.0
Limited Adoption
Selected cases viable

4.1 - 5.0
Ready for Scaling
Broad adoption suitable

05 Stakeholder-Indicator Mapping & Responsibility Matrix

Responsibility Matrix Overview

Technological Readiness
4 Indicators

Primary: 3DCP Technology Firms

Supporting: Architects, Contractors, Government

Responsibility: Machine-process interface, software compatibility, system openness

Technical & Constructability
7 Indicators

Primary: 3DCP Firms, Structural Engineers, Contractors

Supporting: Architects, Government

Responsibility: Material performance, structural validation, site execution, quality control

Economic Readiness
6 Indicators

Primary: Developers, Contractors

Supporting: 3DCP Firms, Financial Institutions

Responsibility: Investment decisions, productivity, market demand, cost management

Business, Policy & Commercial
7 Indicators

Primary: Government/Regulators

Supporting: Financial Institutions, Developers, Contractors

Responsibility: Standards, approvals, procurement, financing, insurance

Integration Logic

1. Each indicator scored on 1-5 readiness scale
2. Low-scoring indicators identified
3. Primary stakeholder traced from matrix
4. Supporting stakeholders noted
5. Intervention measures suggested based on responsibility

Example: Score-to-Responsibility

Regulatory Framework
Score: 1

Primary: Government/Regulators

Action: Develop standards & clarify codes

Market Demand
Score: 2

Primary: Developers/Clients

Action: Initiate pilot projects & awareness

Capital Cost
Score: 2

Primary: Developers/Clients

Action: Explore phased investment models

Skilled Workforce
Score: 2

Primary: Contractors

Action: Organize training programs

05 Framework Application: Working Example

Project Context

Location:
Ahmedabad, Gujarat

Type:
G+1 Affordable Housing (Demo)

Stakeholders:
Developer, Tech Firm, Contractor, Engineer, Architect, Municipality, Financier

Dimension Weights

Technological	0.15
Technical	0.25
Economic	**0.35**
Business/Policy	0.25

Justification based on stakeholder interviews

Final Calculation

$$ORS = (2.50\times0.15) + (2.29\times0.25) + (2.50\times0.35) + (1.71\times0.25)$$

$$= 0.375 + 0.5725 + 0.875 + 0.4275 = 2.25 / 5.0$$

Indicator Scoring by Dimension

Technological — 2.50

Printer-process integration	3
Digital workflow	2
Interoperability	3
Proprietary systems	2

Interpretation: Usable for pilot, lacks full standardization

Technical — 2.29

Material rheology	3
Interlayer bond	2
Structural reliability	2
Durability	2
QC framework	2
Site execution	3
Skilled workforce	2

Interpretation: Possible but needs build confidence

Economic — 2.50

Capital cost	2
Material cost	2
Productivity	3
Market demand	3

Interpretation: Some promise, weak cost case

Business/Policy — 1.71

Regulatory framework	1
Tender integration	2
Approval clarity	2
Financing	2
Insurance	1
Scalability	2
Contracts	2

WEAKEST DIMENSION

Final Interpretation: PILOT STAGE

Score 2.25 (Range 2.1-3.0)

Main Barriers:
No standards · Weak insurance · High cost

06 Key Contributions & References

Main Contributions

1. **Bridges Research Gap**
   Moves beyond simple barrier listing to empirical validation within Indian contractor ecosystem

2. **Measurable Assessment**
   Provides 14 indicators with 5-point scoring system for quantitative readiness evaluation

3. **Responsibility Allocation**
   Links 29 barriers to 7 stakeholder groups, enabling targeted interventions

4. **Decision Support**
   Helps identify intervention priorities with score-to-responsibility mapping

5. **Scalability**
   Can be applied across contexts, project types, and future emerging technologies

Framework Summary

"The proposed Stakeholder-Driven, Barrier-Driven 3DCP Adoption Readiness Framework integrates technical, economic, and institutional dimensions with stakeholder responsibilities to evaluate and improve the adoption potential of 3D concrete printing in the Indian construction industry."

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Thank You

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