

Circulation Efficiency and Functional Zoning of South Gujarat ITI Campuses

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Abstract

Effective spatial organization through logical circulation systems and functional zoning is essential for optimizing vocational training environments. This comparative study examines circulation efficiency and functional zoning patterns across three government Industrial Training Institutes (ITIs) in South Gujarat—Palsana, Navsari, and Bilimora—representing three distinct institutional typologies: ring-like passage, courtyard-centered, and linear industrial configurations. Using measured field data, site plan analysis, and comparative spatial documentation, the research evaluates circulation metrics, functional zoning logic, and design typology performance. Field measurements and stakeholder surveys validate spatial findings. Results demonstrate that ITI Navsari's courtyard-centered typology achieves optimal zoning coherence and circulation fluidity. ITI Palsana's ring-like passage system provides controlled circulation but creates navigation complexity and congestion at junction points. ITI Bilimora's linear industrial model maximizes workshop continuity but sacrifices functional zoning clarity and creates extended evacuation distances. The study establishes that institutional massing typology fundamentally determines circulation performance and zoning coherence. Courtyard-centered designs emerge as optimal for multi-trade vocational training, supporting safe multi-directional movement, logical functional separation, and equitable access across campus zones.

Keywords: Circulation Efficiency; Functional Zoning; Campus Typology; ITI Design; Spatial Organization.

1. Introduction

The spatial efficiency of vocational training institutions is fundamentally shaped by two interconnected architectural strategies: circulation efficiency and functional zoning. Circulation systems—encompassing corridor widths, pathway configurations, circulation lengths, and movement hierarchy—determine the fluidity of student and staff movement, emergency evacuation capability, and daily operational continuity. Functional zoning—the spatial separation and logical adjacency of administrative, academic, workshop, and support zones—influences noise control, pedagogical separation, operational supervision, and institutional coherence.

Industrial Training Institutes across India accommodate 5.5 million trainees annually, yet infrastructure planning frequently prioritizes compliance with minimum area norms (NCVT standards) over systematic circulation and zoning design. Consequently, many government ITIs exhibit fragmented spatial organization, inefficient movement patterns, and compromised functional separation—limiting training quality and workplace safety.

The South Gujarat region encompasses three government ITIs (Palsana, Navsari, Bilimora) serving textile, engineering, chemical, and fabrication clusters. Preliminary assessment suggests significant variation in circulation and zoning effectiveness across these institutions, reflecting different institutional histories, design philosophies, and campus configurations.



Figure 1: Map showing the South Gujarat Region with locations of the three studied ITI campuses (Palsana, Navsari, Bilimora).

Research Aim: The aim of this research is to evaluate the spatial and functional performance of government Industrial Training Institutes (ITIs) in South Gujarat and to examine how architectural planning and built-environment parameters influence vocational training quality, safety, workflow efficiency, and the formation of professional skill identity among trainees.

2. Literature Review

Previous research in educational facility planning emphasizes the importance of circulation design in ensuring safety, wayfinding clarity, and operational efficiency. Studies on school and university campuses highlight that wider corridors, multi-directional movement paths, and visual connectivity significantly improve user experience and emergency responsiveness. Neufert's architectural standards underline minimum corridor dimensions and zoning separation principles for industrial and educational buildings, stressing the need for adjacency between functionally related spaces such as workshops and storage areas.

In technical and vocational education facilities, zoning plays a crucial role in managing noise, dust, and safety hazards associated with heavy machinery. Research indicates that clustering compatible trades and isolating noise-intensive activities enhance both pedagogical effectiveness and occupational safety. Courtyard-centered planning models have been widely

recognized for promoting natural wayfinding, social interaction, and flexible circulation in institutional environments. Conversely, linear industrial layouts are often favored in manufacturing facilities for workflow efficiency but present challenges when applied to multi-functional educational campuses.

Despite extensive guidelines on minimum spatial provisions, limited comparative studies analyze how campus typology directly impacts circulation performance and zoning coherence in vocational training institutions. Most infrastructure assessments focus on area compliance rather than experiential efficiency. This research addresses this gap by systematically evaluating spatial metrics and user perceptions across distinct ITI typologies.

3. Objectives

This study examines the following objectives:

- How circulation typology (ring-like, courtyard-centered, linear) influences movement efficiency, safety, and operational performance in multi-trade vocational training environments.
- How functional zoning strategies segregate incompatible uses (noisy trades vs. quiet labs) and facilitate logical adjacency (workshop-storage, administrative-reception) across campus.
- Comparative performance of three distinct massing typologies against NCVT norms and occupational standards.
- Evidence-based design recommendations for optimizing circulation and zoning in future ITI development.

4. Research Methodology

This study employs a comparative case study approach to analyze circulation efficiency and functional zoning across three government ITI campuses in South Gujarat representing courtyard-centered, ring-like, and linear typologies. Primary data was collected through on-site spatial measurements of corridor widths, circulation lengths, exits, and built-up area distribution, supported by architectural plan analysis. User perception was assessed through structured surveys of management, faculty, and students using a five-point Likert scale. Circulation and zoning performance were evaluated against National Building Code and NCVT standards. Comparative analysis identified spatial efficiency trends across the three institutional layouts.

This comparative study integrated three data streams:

Spatial Measurements (Primary Field Data):

- Measured corridor widths and circulation lengths using 50 m measuring tapes and electronic distance meters.
- Documented main corridor lengths (45–85 m), secondary corridor widths (2.0–3.5 m), staircase dimensions, and emergency exit locations.
- Recorded building footprints, floor-to-floor heights, and site area coverage.

- Identified functional zoning patterns (administrative placement, workshop clustering, support area distribution).

Plan Analysis:

- Architectural drawings provided by institutional management; site plans documented floor layouts, massing arrangements, and circulation spine configurations.
- Identified three distinct typologies: ring-like passage circulation (Palsana), courtyard-centered massing (Navsari), and linear industrial hall configurations (Bilimora).

Stakeholder Assessment:

- Management Survey (n=18): 5-point Likert-scale assessment of internal circulation effectiveness, clarity of block connections, frequency of operational spatial constraints, and zoning adequacy.
- Faculty Survey (n=28): Assessment of visibility across blocks, ease of movement during demonstrations, and circulation maintaining order.
- Student Survey (n=89): Evaluation of ease of movement, clarity of entry-exit points, ease of navigation between blocks, and frequency of spatial constraints.

5. Research Problem

Despite meeting minimum infrastructure norms, many ITI campuses exhibit inefficient circulation systems and unclear functional zoning, resulting in congestion, safety risks, and reduced training effectiveness. There is limited empirical research evaluating how institutional typology influences spatial performance in vocational education environments. This study seeks to address this gap through a comparative spatial analysis of three South Gujarat ITIs representing distinct massing typologies.

6. Analysis and Interpretation / Findings

6.1 ITI Navsari: Courtyard-Centered Circulation Typology

ITI Navsari employs a courtyard-centered massing strategy with peripheral workshop zones arranged around a central circulation court (approximately 30 m × 25 m). This typology creates multi-directional pedestrian movement pathways radiating from the courtyard hub.

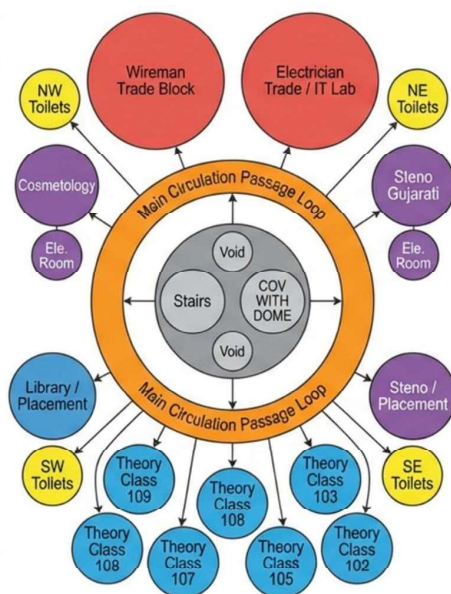


Figure 2: Functional Zoning and Circulation Relationship Diagram – ITI Navsari.

Metric	Measurement	Standard	Compliance
Main Corridor Length	45 m	≤60 m optimal	✓ Compliant
Main Corridor Width	3.8–4.0 m	≥3.0 m minimum	✓ Exceeds
Secondary Corridor Width	2.8–3.2 m	≥2.0 m minimum	✓ Exceeds
Staircase Width	2.0 m	≥1.5 m	✓ Compliant
Emergency Exits	6 per campus	≥2 per floor	✓ Exceeds
Lobby Area	80 sq.m	≥40 sq.m	✓ Exceeds
Circulation as % Built-up	16%	15–20% optimal	✓ Optimal

Table 1: Measured Circulation Metrics – ITI Navsari

Circulation Characteristics:

- Multi-directional movement pathways enable flexible crowd distribution during peak teaching hours.
- Central courtyard functions as natural wayfinding landmark, reducing navigation confusion.
- Wide primary corridors (3.8–4.0 m) accommodate simultaneous pedestrian and material trolley movement without congestion.
- Visual connectivity across courtyard enhances supervision, emergency monitoring, and inter-block accessibility.

Assessment Area	Rating	Percentage
Management: Circulation Effectiveness	Excellent	83%
Management: Block Connection Clarity	Clear / Moderately Clear	100%
Faculty: Movement During Demonstrations	Very Easy / Manageable	78%
Faculty: Visibility Across Blocks	Adequate / Well	75%
Students: Ease of Navigation Between Blocks	Very Easy / Manageable	83%

Table 2: Stakeholder Performance Ratings – ITI Navsari

6.2 ITI Palsana: Ring-Like Passage Circulation Typology

ITI Palsana utilizes a rectilinear block arrangement with internal ring-like circulation passages connecting workshop clusters. This creates redundant but narrow movement pathways forming a continuous loop around central workshop zones.

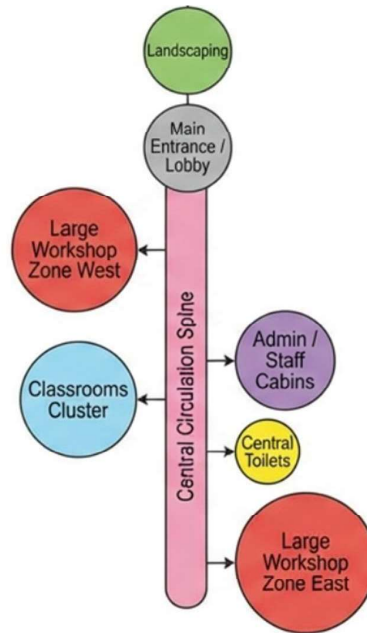


Figure 3: Functional Zoning and Circulation Relationship Diagram – ITI Palsana.

Metric	Measurement	Standard	Compliance
Main Corridor Length	65 m	≤60 m optimal	✗ Exceeds by 5 m
Main Corridor Width	3.0–3.2 m	≥3.0 m minimum	✓ Marginal
Secondary Corridor Width	2.0–2.5 m	≥2.0 m minimum	✓ Minimum threshold
Staircase Width	2.0 m	≥1.5 m	✓ Compliant
Emergency Exits	4 per campus	≥2 per floor	✓ Adequate
Lobby Area	60 sq.m	≥40 sq.m	✓ Adequate
Circulation as % Built-up	14%	15–20% optimal	✗ Below optimal

Table 3: Measured Circulation Metrics – ITI Palsana

Circulation Characteristics:

- Redundant passage system provides alternative circulation routes and evacuation flexibility.
- Narrow secondary passages (2.0–2.5 m) restrict simultaneous two-way movement during peak occupancy, creating bottlenecks at junction points.
- Ring-like configuration increases walking distances; students must traverse lengthy passages for access to workshops at opposite campus ends.
- Limited visual connectivity between workshop clusters restricts faculty supervision effectiveness and inter-block communication.

Assessment Area	Rating	Percentage
Management: Circulation Effectiveness	Adequate / Poor	58%
Management: Block Connection Clarity	Unclear	42%
Faculty: Movement During Demonstrations	Manageable / Difficult	52%
Faculty: Visibility Across Blocks	Poor	46%

Table 4: Stakeholder Performance Ratings – ITI Palsana

6.3 ITI Bilimora: Linear Industrial Circulation Typology

ITI Bilimora employs long linear workshop bays aligned north-south, with a single primary corridor backbone and lateral entry points into individual trade zones. This typology prioritizes functional machining workflow continuity over circulation flexibility.

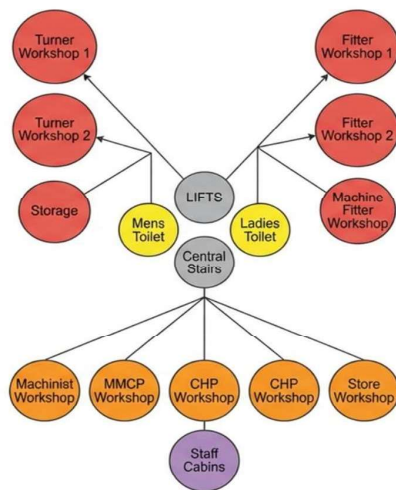


Figure 4: Functional Zoning and Circulation Relationship Diagram – ITI Bilimora.

Metric	Measurement	Standard	Compliance
Main Corridor Length	85 m	≤60 m optimal	X Exceeds by 25 m
Main Corridor Width	2.8–3.2 m	≥3.0 m minimum	✓ Marginal
Secondary Lateral Passages	1.5–2.0 m	≥2.0 m minimum	X Below standard
Staircase Width	2.5 m	≥1.5 m	✓ Exceeds
Emergency Exits	8 per campus	≥2 per floor	✓ Exceeds
Lobby Area	120 sq.m	≥40 sq.m	✓ Exceeds
Circulation as % Built-up	11.60%	15–20% optimal	X Below optimal

Table 5: Measured Circulation Metrics – ITI Bilimora

Circulation Characteristics:

- Linear configuration optimizes interior space for large machining workshops but creates singular circulation dependency.
- Extended primary corridor (85 m) exceeds ergonomic walking efficiency thresholds and extends emergency evacuation times.
- Narrow lateral passages (1.5–2.0 m) create bottleneck conditions at workshop entries/exits, particularly during scheduled trade transitions.
- Restricted visual connectivity along elongated corridors reduces supervision effectiveness, wayfinding clarity, and cross-trade movement.

Assessment Area	Rating	Percentage
Management: Circulation Effectiveness	Poor / Very Poor	42%
Management: Block Connection Clarity	Unclear / Poorly Connected	39%
Faculty: Movement During Demonstrations	Manageable / Difficult	35%
Faculty: Visibility Across Blocks	Poor	39%
Students: Ease of Navigation Between Blocks	Difficult / Very Difficult	37%

Table 6: Stakeholder Performance Ratings – ITI Bilimora

6.4 Functional Zoning Assessment

Functional zoning separates the campus into five primary zones: (1) Administrative (principal office, accounts, reception), (2) Academic (classrooms, lecture theaters), (3) Workshop (practical training spaces by trade), (4) Support (storage, tool rooms, sanitation), and (5) Outdoor (parking, landscaping, future expansion). Effective zoning logic requires clear separation of incompatible uses, logical adjacency of related spaces, equitable access from main circulation, and support area integration without disrupting workflow.

ITI Navsari: Balanced Multi-Zone Organization

Zone	Location	Area (sq.m)	Adjacency Logic	Performance
Administrative	Outer periphery	138	Reception entry, away from workshops	✓ Excellent
Academic	Courtyard upper floor	652	Central, visible from courtyard	✓ Excellent
Workshop	Courtyard perimeter	754	Around central court, logical separation	✓ Excellent
Support (Storage)	Adjacent to workshops	74	Tool rooms integrated with trades	✓ Good
Sanitation	Multiple points	60	Dispersed, accessible from courtyard	✓ Good

Table 7: Functional Zoning Analysis – ITI Navsari

Faculty Assessment: 92% reported zoning adequately supports pedagogical isolation of incompatible trades.

ITI Palsana: Moderate Zoning with Separation Strengths

Zone	Location	Area (sq.m)	Adjacency Logic	Performance
Administrative	Front edge/foyer	180	Entry-oriented, visible	✓ Adequate
Academic	Side blocks	450	Separate from workshop noise	✓ Adequate
Workshop	Central dense cluster	1,800	Tightly organized but congested	✗ Adequate
Support	Peripheral	85	Undersized, inadequate	✗ Poor

COPA Lab	Isolated block	70	Acoustically separated from welding	✓ Good
Sanitation	Multiple locations	45	Adequate coverage	✓ Adequate

Table 8: Functional Zoning Analysis – ITI Palsana

Faculty Assessment: 64% reported adequate zoning, but 36% noted unclear separation between adjacent incompatible trades.

ITI Bilimora: Industrial Zoning with Functional Coherence

Zone	Location	Area (sq.m)	Adjacency Logic	Performance
Administrative	Edge of campus	250	Peripheral, away from noise	✓ Good
Heavy Trades Core	Central linear block	3,500	Turner, Machinist, CHP consolidated	✓ Excellent
Light Trades / Academic	Separate block	800	Isolated from heavy machining	✓ Adequate
Support (Storage)	Along workshop spine	180	Integrated with machining zone	✓ Good
Sanitation	Multiple dispersed	80	Adequate coverage	✓ Adequate
Outdoor	Extensive	10,687	Large unbuilt 30%, but underutilized	✗ Underutilized

Table 9: Functional Zoning Analysis – ITI Bilimora

Faculty Assessment: 78% rated zoning clear and functional for primary trades; 22% noted insufficient zoning flexibility for emerging trades.

6.5 Typological Performance Matrix

Performance Dimension	Navsari (Courtyard)	Palsana (Ring)	Bilimora (Linear)
Circulation Efficiency			
Corridor Width Adequacy	Excellent (3.8–4.0 m)	Adequate (3.0–3.2 m)	Marginal (2.8–3.2 m)

Circulation Length	Optimal (45 m)	Acceptable (65 m)	Excessive (85 m)
Multi-directional Movement	Excellent	Good	Limited
Wayfinding Clarity	Excellent	Good	Adequate
Functional Zoning			
Administrative Isolation	Excellent	Adequate	Good
Noisy/Quiet Separation	Excellent	Good	Adequate
Storage Adjacency	Good	Poor	Good
Sanitation Accessibility	Good	Adequate	Adequate
Flexibility for Multiple Trades	Excellent	Adequate	Limited
Faculty Supervision Capability	75% adequate	54% adequate	39% adequate
Student Movement Ease	83% positive	59% positive	37% positive
Management Circulation Assessment	83% satisfactory	58% satisfactory	42% satisfactory
Operational Spatial Constraints	16% report	31% report	48% report

Table 10: Comparative Typological Performance Matrix

6.6 Typology Selection Framework

Institutional Context	Recommended Typology	Rationale
Multi-trade (4+ trades), mixed enrollment	Courtyard	Multi-directional movement, flexible zoning, superior supervision
Single dominant trade, compact site	Ring-like	Redundant routes, efficient footprint, clear boundary
Specialized sector (machining/fabrication), large site	Linear	Production workflow alignment, occupant efficiency

Table 11: Typology Selection Framework for ITI Design Contexts

7. Conclusion

Circulation efficiency and functional zoning are architectural determinants of vocational training institution performance, directly influencing movement fluidity, safety, operational efficiency, and pedagogical quality. This comparative analysis across three government ITIs in South Gujarat establishes that institutional massing typology fundamentally shapes circulation and zoning outcomes.

The Courtyard-Centered Typology (ITI Navsari) emerges as optimal for multi-trade educational ITIs, delivering superior circulation efficiency (45 m spine, 3.8–4.0 m corridors, 6 exits, multi-directional access), balanced functional zoning, and the highest stakeholder satisfaction ratings (83% management, 75% faculty, 83% students). The Ring-Like Typology (ITI Palsana) provides moderate performance with controlled but complex circulation, achieving 58% management and 59% student satisfaction, and is most suitable for medium-scale institutions with a single dominant trade. The Linear Typology (ITI Bilimora) is best suited for specialized single-sector industrial training, with clear heavy/light trade separation but the lowest stakeholder satisfaction (42% management, 37% students) due to its extended corridor length and limited flexibility for multi-trade diversity.

8. Suggestions / Recommendations

- Establish circulation and zoning standards as mandatory components of ITI infrastructure development, supplementing current area-based NCVT norms.
- Prioritize courtyard-centered or atrium-based typologies for new multi-trade ITI construction in South Gujarat, with primary corridors of ≥ 3.5 m and maximum circulation spines of ≤ 60 m.
- For existing linear-typology institutions such as ITI Bilimora, introduce intermediate transverse corridors, mid-spine exits, and zoning restructuring to improve circulation performance.
- Implement institutional-level circulation audits and zoning assessments as part of NCVT accreditation processes.
- Acoustic zoning protocols should mandate a minimum 20 m buffer distance or physical barriers between noise-generating and quiet trade zones.
- Administrative zones should occupy 5–8% of campus area and be entry-oriented; workshop zones should occupy 40–50%, clustered by trade compatibility.

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