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EVALUATION OF TUNNEL FORM SYSTEM FOR CONDOMINIUMS AND HORIZONTAL HOUSING PROJECTS: STANDARDIZING TUNNEL FORM SYSTEM IN CONSTRUCTION HOUSING PROJECTS

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Abstract

The Tunnel Form System (TFS) has emerged as an innovative construction technology designed to enhance efficiency, structural quality, and safety in mid- to high-rise building projects. This study evaluates the extent to which TFS offers advantages over traditional and other construction methods in terms of time efficiency, cost implications, labor requirements, dimensional accuracy, structural uniformity, concrete finish quality, and overall site safety, with a view toward standardizing its use in Philippine condominium and horizontal housing construction. Using a descriptive, mixed-method (triangulated) design, the study integrates quantitative survey data from 41 construction professionals with qualitative insights from semi-structured interviews and site observations of TFS implementation. Findings show that TFS significantly accelerates project timelines through its repetitive, monolithic wall-and-slab casting process, which reduces cycle time and formwork-related delays. Although the initial investment in TFS is higher than for traditional formwork, respondents reported long-term savings from reduced labor dependency, lower material wastage, and fewer dimensional inconsistencies requiring rework. Respondents also reported improvements in structural uniformity, concrete finish quality, and on-site safety, attributed to the precision-engineered steel forms and to the safety controls that mechanized lifting operations require. Sustainability considerations pointed to reduced waste generation and improved resource efficiency from formwork reuse. The study concludes that the Tunnel Form System offers substantial operational, economic, and safety benefits that can support the Philippine construction industry's demand for faster, safer, and more sustainable housing delivery, provided that its adoption is supported by technical standards, a specialized skills-training program, and site-selection guidelines that account for its limitations on irregular or sloped sites. Because the findings rest on perception-based survey and interview data rather than verified project records, they should be read as an evaluation of practitioner experience rather than an audited cost-benefit analysis; an expanded cost-benefit analysis across building types and an evaluation of long-term structural performance under local conditions are recommended for future research.

Keywords: *Tunnel Form System; formwork standardization; construction management; mixed-methods research; Philippine housing construction; time efficiency; cost implications*

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INTRODUCTION

Background of the Study

Rapid urbanization and population growth continue to outpace housing supply in the Philippines. The Philippine Statistics Authority has documented population growth that exceeds the development of adequate housing and urban infrastructure, and the National Economic and Development Authority has identified a persistent housing backlog of several million units. Condominiums and horizontal housing developments — townhouses, subdivisions, and gated communities — have become the primary vehicles for closing this gap, but traditional cast-in-place construction remains labor-intensive, time-consuming, and prone to inconsistent workmanship, high formwork wastage, and weather-related delays.

The Tunnel Form System (TFS) is an industrialized alternative that casts reinforced-concrete walls and slabs monolithically, enabling rapid, repeatable daily construction cycles. Its adoption in the Philippines remains limited; one frequently cited local account (Pascual, 2013) [unverified — not in reference list] reports that Tunnel Formwork requires a higher upfront investment but becomes more cost-efficient with repeated use, reducing both labor requirements and construction duration. This study examines whether TFS offers measurable advantages over traditional methods for Philippine condominium and horizontal housing projects, and what would be required to standardize its use.

Statement of the Problem

Traditional formwork practices remain labor-intensive and highly dependent on skilled trades at every stage, which creates delays where labor or expertise is scarce and produces dimensional and finish inconsistencies from repeated assembly and disassembly of formwork. TFS promises faster, more consistent, and safer construction, but it requires significant investment in equipment and specialized personnel, and its feasibility relative to traditional methods in the Philippine context has not been systematically documented. Specifically, this study sought to answer:

- How does the Tunnel Form System compare with traditional and other construction methods for condominiums and horizontal housing projects in terms of time efficiency, cost implications, labor and skill requirements, quality and accuracy, and safety and waste management?
- To what extent does the Tunnel Form System reduce overall project timelines compared to traditional construction methods?
- What are the differences in initial investment and long-term costs between the Tunnel Form System and conventional construction methods?
- What limitations or constraints exist when applying the Tunnel Form System to different building types, layouts, and architectural designs?
- What set of guidelines or standard procedures can be formulated to support the standardization of the Tunnel Form System in condominium and horizontal housing construction projects?

Hypotheses

The null hypothesis (H_0) posits no significant difference between TFS and traditional/other construction methods in terms of time efficiency, cost, labor requirements, quality, safety, adaptability, and implementation challenges. The alternative hypothesis (H_1) posits that TFS offers significant improvements in one or more of these respects — most notably reduced construction time, improved labor productivity, higher initial but lower long-term cost, and improved efficiency and quality once standardized.

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Theoretical and Conceptual Framework

The study draws on the Construction Technology Adoption Theory (CTAT), which holds that firms adopt a new system such as TFS when its perceived performance advantages — faster cycles, improved quality, reduced rework — outweigh the risks of high initial investment and the organizational readiness it demands (financial resources, skilled personnel, equipment). It is complemented by the Technology Acceptance Model (TAM; Davis, 1986, 1989), which explains adoption through Perceived Usefulness and Perceived Ease of Use, which shape Attitude Toward Use, Behavioral Intention, and ultimately Actual Adoption. Both frameworks converge on the same implication for this study: adoption depends on clear, repeatable, well-documented procedures, which is the basis for the study's emphasis on standardization.

The conceptual framework follows an Input–Process–Output (IPO) model. Inputs are the current comparative performance of TFS against traditional methods (time, cost, labor, quality, safety) drawn from literature, interviews, and site observation. The process is the analysis and interpretation of survey and interview data using construction-management principles. The output is a set of proposed technical standards, policy recommendations (including a possible Department Order), and a specialized skills-training program to support standardized TFS adoption in Philippine housing construction.

Review of Related Literature

Speed of construction

TFS is used extensively in India, Turkey, Japan, and the Middle East for mass housing, but remains underused in the Philippines. Its speed advantage comes from casting walls and slabs simultaneously in a monolithic pour, eliminating the sequential activities that slow traditional formwork (Vallabhy et al., 2018). Comparative data from India show tunnel formwork achieving an average pour cycle of roughly three days per floor versus seven to ten days for aluminum formwork (Ashwin & Paul, 2025). Realizing this advantage in practice depends on disciplined workflow sequencing, equipment readiness, and trained manpower (Varade & Mata, 2024 — unverified).

Labor requirement

TFS reduces overall labor headcount but raises the skill bar: mechanized, repetitive casting favors small, technically proficient crews over large manual formwork teams (Varade & Mata, 2024; Shalgar & Aradhye, 2017 — unverified), a shift corroborated by comparative studies of aluminum and tunnel formwork (Ashwin & Paul, 2025).

Formwork reusability

TFS panels are fabricated from high-strength steel capable of hundreds of reuse cycles, which reduces embodied energy and waste relative to consumable plywood formwork as cycle count increases (Balasbaneh et al., 2024 — unverified).

Cost implications

TFS carries a higher initial investment than traditional or aluminum formwork, but becomes the most cost-effective option once a project reaches roughly 450–500 reuse cycles (Ashwin & Paul, 2025). Traditional formwork can represent 20–25% of total project cost, and its longer duration compounds overhead and labor expense (Varade & Mata, 2024 — unverified); broader comparative work likewise concludes that TFS ultimately produces a lower cost per unit through shorter durations and reduced labor demand (Lodha & Tambe, 2017 — unverified). In the Philippines, this upfront cost is frequently cited as the principal barrier to adoption,

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compounded by short-term budgeting practices and limited local awareness of lifecycle cost analysis (Select Structural, 2023 — unverified).

Limitations of the Tunnel Form System

Cost recovery depends on repeated reuse, so TFS is financially favorable mainly for large, repetitive developments; low-repetition or small-scale projects may not reach the break-even point (İlerisoy & Tuna, 2018; Kanoğlu, n.d.). Building geometry matters as well — TFS performs best with repetitive, symmetrical layouts and is less cost-effective for low-rise or irregular buildings (İlerisoy & Tuna, 2018). Seismic design guidance specific to tunnel-form buildings also remains limited in some contexts, with engineers often relying on generalized reinforced-concrete methods (Hadjadj et al., 2025), reinforcing the case for localized technical standards and quality-control protocols alongside adoption.

Tunnel Form System in the Philippines

The small number of Philippine firms using TFS limits the pool of practitioners who can share operational insight, which slows the industry's learning curve (Pascual, 2013 — unverified). This scarcity of local benchmark projects and field data is the central gap this study addresses.

Significance of the Study

The study is intended to help developers and contractors weigh the cost, efficiency, and sustainability trade-offs of adopting TFS for repetitive housing designs; to support government agencies and training institutions in developing technical standards, policy guidance, and workforce-development programs for the system; and to contribute empirical, Philippine-specific evidence to a literature that is presently dominated by South Asian and Middle Eastern case studies.

Scope and Limitations

The study is confined to mid-rise condominiums and horizontal housing developments within the Philippines; its findings may not generalize to high-rise buildings, industrial facilities, other countries, or building types with materially different structural requirements. Data come from 41 respondents from firms that use TFS, from published literature, and from site observation — not from proprietary project cost records or productivity logs, which were unavailable. The relatively small population of Philippine TFS practitioners constrains the representativeness of the sample, and the proposed technical standards and policy recommendations are based on available stakeholder input and would require further validation through broader industry consultation or pilot implementation.

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METHODS

Research Design

The study used a descriptive research design supported by a mixed-method (triangulated) approach, drawing exclusively on data gathered directly from respondents and site observation; no project records or construction logs were used. The design combined a structured survey (perception-based quantitative ratings of speed, cost behavior, safety, labor requirements, and formwork reusability), semi-structured interviews (qualitative accounts of challenges, workflow, and feasibility), and field observation of TFS operations from layout through stripping.

Respondents

Forty-one construction professionals directly involved in TFS projects participated: project managers, project-in-charge personnel, site/project engineers, and safety officers. These roles were purposively selected because each holds a distinct vantage point on TFS performance — project managers on schedule, budget, and coordination; project-in-charge personnel on daily execution and quality verification; site engineers on technical design and materials compliance; and safety officers on hazard identification, PPE compliance, and emergency response.

Research Instrument

A four-part survey questionnaire was administered: Part I collected respondent profile data (company, age, gender, position, years of experience); Part II asked respondents to rate TFS on a five-point Likert scale across speed/time, cost behavior, safety, labor requirements, and formwork usability/reusability; Part III captured open-ended responses on challenges encountered and suitability for mid-rise and horizontal housing; and Part IV captured general feedback on future adoption intent. The same broad themes structured the semi-structured interview guide used with key personnel.

Data Collection Procedure

Data were gathered through structured surveys, semi-structured interviews with key personnel, and direct site visits and observation of TFS workflow — form setup, rebar and MEPF installation, concrete pouring, curing, and stripping — supplemented by informal on-site discussions that provided real-time context for the interview and survey findings.

Data Analysis

Quantitative survey responses were scored on a five-point scale and summarized as weighted means with the following verbal interpretation: 1.00–1.79 Not Agree, 1.80–2.59 Disagree, 2.60–3.39 Somewhat Agree, 3.40–4.19 Agree, and 4.20–5.00 Strongly Agree. Qualitative interview data were reviewed for recurring patterns, grouped into thematic categories (e.g., positive, neutral, and negative comments), sub-categorized by theme, and summarized to identify dominant trends, which were then triangulated against the quantitative results.

Ethical Considerations

The study observed voluntary participation, informed consent, and anonymity and confidentiality of respondents, all of whom were drawn from the local construction sector; results were communicated back to participating organizations in aggregate, non-attributable form.

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RESULTS

Demographic Profile of Respondents

Table 1. Age Distribution of Respondents (n = 41)

Age Range	f	%
23–30 years old	11	26.83
31–40 years old	20	48.78
41–50 years old	3	7.32
51–60 years old	7	17.07
61 years old and above	0	0.00
Total	**41**	**100.00**

Nearly half of the respondents (48.78%) were 31–40 years old, and a further 26.83% were 23–30 — together, over three-quarters of the sample falls within early-to-middle adulthood. No respondents were 61 or older, and only 7.32% were 41–50. The results therefore reflect the perspectives of working-age professionals rather than late-career or retired practitioners, a bias worth bearing in mind when generalizing the findings.

Table 2. Position of Respondents in the Company (n = 41)

Position	f	%
Project Engineer	26	63.42
Safety Officer	8	19.51
Project in Charge / Manager	7	17.07
Project Director	0	0.00
Total	**41**	**100.00**

Project Engineers made up nearly two-thirds of respondents, with Safety Officers and Project-in-Charge/Managers making up the remainder; no Project Directors were surveyed. The sample is therefore weighted toward operational and technical-supervision perspectives rather than executive or strategic ones, which strengthens the study's relevance to day-to-day implementation but limits its insight into corporate-level adoption decisions.

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Table 3. Years of Construction-Industry Experience (n = 41)

Years of Experience	f	%
0–10 years	20	48.78
11–20 years	19	46.34
21–30 years	2	4.88
31 years and above	0	0.00
Total	**41**	**100.00**

More than 95% of respondents had 20 years of experience or less, indicating a sample drawn largely from professionals trained on contemporary construction practice and safety standards, with very limited representation of veteran (21+ year) practitioners.

Qualitative Findings: Interviews with Key Personnel

Speed of construction

Personnel consistently described TFS as a high-speed method suited to repetitive residential projects, crediting simultaneous wall-and-slab casting for predictable, sometimes daily, casting-and-stripping cycles. One project-in-charge/project manager reported delivering nearly 500 rowhouse and townhouse units in a South Luzon development within three months, using Tunnel Forms redesigned to fit the project's unit layout. A finishing engineer likewise credited TFS with faster unit turnover for finishing trades, though noted that window-opening dimensions could be affected if form installation was not executed carefully — an issue attributed to workmanship rather than the system itself.

Cost and savings

Interviewees did not have access to formal cost data but consistently pointed to three cost-related benefits: reduced finishing requirements (walls typically ready for skim coat immediately after stripping), lower manpower demand (small specialized crews for casting, stripping, and cycling), and reduced rework and waste. One South Luzon low-to-medium-cost housing project reportedly achieved approximately ₱20–25 million in savings through continuous TFS use combined with an MEPF layout re-designed to match formwork dimensions — an outcome respondents attributed to strong coordination between the construction team and management as much as to the system itself.

Safety

Because TFS relies heavily on cranes and heavy steel formwork, respondents described a higher-risk operating environment requiring additional controls beyond standard site protocols: stricter exclusion zones, routine inspection of lifting equipment, and enhanced supervision during lifting and form movement. One safety officer credited daily toolbox meetings and weekly safety-awareness sessions, together with coordination with a

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centralized mechanical team that validates crane-operator and rigger certifications, with reinforcing safe practice during high-risk operations.

Labor skill requirements

Respondents were unanimous that TFS reduces headcount but raises the skill floor: untrained crews risk wall misalignment, plumbness issues, surface defects, and lifting-related safety incidents. A plant engineer noted that no formal Philippine certification currently exists for TFS operations, though internal trade testing is used to screen personnel, and that a welding certification is an advantage given the steel components involved. Respondents suggested that a dedicated national training or certification track for alignment, form-striking, rigging, and equipment handling would strengthen both safety and quality outcomes.

Formwork usability and reusability

All interviewees identified the durability of steel Tunnel Forms — in contrast to consumable plywood and phenolic formwork — as a major advantage, citing reduced construction waste, lower reliance on disposable materials, and cleaner, more predictable worksites.

Design coordination and site limitations

TFS performed best on highly repetitive layouts; personnel described added difficulty on projects with complex floor configurations, varying elevations, sloping terrain, or beam-and-column systems, which complicate kicker installation, concrete placement, and safe crane setup. A survey engineer described sloping or uneven sites as particularly challenging for crane stabilization and form alignment, noting that some units or building segments reverted to alternative construction methods where TFS was not feasible — while adding that strong coordination and timely decision-making generally kept overall project phasing on track despite these constraints.

MEPF coordination

Mechanical, electrical, plumbing, and fire-protection (MEPF) coordination emerged as a critical success factor. When TFS is the primary structural method from the outset, MEPF teams reported smoother integration and gains from prefabrication of components aligned to the fixed, repetitive wall-and-slab layout, reducing on-site cutting and material waste. Where TFS is used only partially, MEPF teams instead had to adapt rough-ins, block-outs, and embed locations to the Tunnel Form casting sequence — workable, respondents said, but dependent on early and thorough coordination meetings.

Quantitative Assessment

A structured survey captured practitioners' quantitative assessment of TFS across five dimensions, complementing and triangulating the interview findings. International literature similarly frames TFS as suited to mass and repetitive housing because of its standardized, repeatable process (Miranda & Kodre, 2018; Ray et al., 2020).

Scale: 1.00–1.79 Not Agree | 1.80–2.59 Disagree | 2.60–3.39 Somewhat Agree | 3.40–4.19 Agree | 4.20–5.00 Strongly Agree

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Table 4. Speed of Construction on a Daily Cycle

Indicative Statement	Weighted Mean	Verbal Interpretation
1.1 Tunnel Form casting (setup) can be completed within a standard 8-hour shift.	4.59	Strongly Agree
1.2 Rebar and utilities layout can be completed within 8 hours following form casting.	4.64	Strongly Agree
1.3 Concrete pouring is completed within the 24-hour construction cycle.	4.77	Strongly Agree
1.4 Stripping of forms is achievable within a 24-hour cycle, subject to concrete strength.	4.51	Strongly Agree
Overall Weighted Mean	**4.63**	**Strongly Agree**

All four indicators scored in the Strongly Agree range, with concrete pouring rated highest (4.77) and form stripping lowest but still Strongly Agree (4.51). Respondents were highly confident that TFS supports a genuine 24-hour construction cycle when concrete supply, equipment, and trade coordination are well managed.

Table 5. Labor Requirement Comparison

Indicative Statement	Weighted Mean	Verbal Interpretation
2.1 TFS demands a higher level of skilled labor for casting, alignment, and stripping than traditional methods.	4.59	Strongly Agree
2.2 TFS demands a greater number of non-skilled laborers than traditional methods.	3.36	Somewhat Agree
2.3 TFS has a greater impact on manhour/labor cost than traditional methods.	3.95	Agree
Overall Weighted Mean	**3.97**	**Agree**

Respondents strongly agreed that TFS raises the demand for skilled labor (4.59) while only somewhat agreeing that it raises demand for non-skilled labor (3.36) — consistent with a shift from labor volume to labor competency. They agreed, more moderately, that this shift increases manhour cost (3.95), reflecting higher wage rates for skilled trades even as total headcount falls.

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Table 6. Safety Aspects

Indicative Statement	Weighted Mean	Verbal Interpretation
3.1 Safety orientation and toolbox meetings are conducted before and throughout work.	4.87	Strongly Agree
3.2 The company provides and strictly monitors PPE compliance.	4.82	Strongly Agree
3.3 Lifting and placement of Tunnel Form units are supervised by certified riggers and crane operators.	4.82	Strongly Agree
3.4 TFS reduces overall safety risk compared to traditional methods.	4.18	Agree
Overall Weighted Mean	**4.67**	**Strongly Agree**

Safety-process indicators (training, PPE, certified operators) all scored above 4.8, reflecting strong procedural discipline on TFS sites. The comparatively lower score for the broader claim that TFS reduces overall risk relative to traditional methods (4.18, still Agree) suggests respondents view TFS as well-controlled rather than inherently risk-free — heavy lifting and mechanized operations introduce their own hazard profile even as they remove others.

Table 7. Formworks Reusability

Indicative Statement	Weighted Mean	Verbal Interpretation
4.1 TFS demonstrates consistent durability from project initiation to completion.	4.74	Strongly Agree
4.2 TFS significantly lowers expenses related to wood-formwork operations.	4.51	Strongly Agree
4.3 TFS reduces construction waste through repeated reuse, promoting sustainable practice.	4.49	Strongly Agree
Overall Weighted Mean	**4.58**	**Strongly Agree**

All three reusability indicators scored above 4.4, with respondents rating durability across the full project cycle highest (4.74). Reuse-driven savings on wood-formwork costs and waste reduction were both rated Strongly Agree, reinforcing formwork reuse as a source of both economic and sustainability benefit.

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Table 8. Cost Implications

Indicative Statement	Weighted Mean	Verbal Interpretation
5.1 TFS requires a high initial investment cost compared to traditional formwork.	4.74	Strongly Agree
5.2 TFS maintenance cost is relatively low due to durability and reusability.	4.31	Strongly Agree
5.3 TFS reduces overall labor cost through faster cycles and simplified operations.	4.51	Strongly Agree
5.4 Specialized equipment (tower/mobile cranes, boom trucks) significantly raises project cost.	4.54	Strongly Agree
Overall Weighted Mean	**4.53**	**Strongly Agree**

Respondents strongly agreed that TFS carries a high initial investment (4.74) and requires costly specialized equipment (4.54), but also strongly agreed that maintenance cost is low (4.31) and that labor cost falls (4.51) once operating. The pattern is consistent across all five assessment tables: TFS is perceived as front-loaded in cost and skill demand, but efficient, durable, and comparatively low-risk once a project is running.

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DISCUSSION

Speed and scheduling

The near-unanimous Strongly Agree ratings for daily-cycle indicators (Table 4), together with the South Luzon case of nearly 500 units delivered in three months, corroborate international findings that TFS compresses floor-cycle time relative to conventional or even aluminum formwork (Ashwin & Paul, 2025). Under the Construction Technology Adoption Theory, this is the clearest "perceived-usefulness" driver of adoption identified in the study: respondents consistently linked faster cycles to compressed schedules and, in some cases, early completion (Tam, Soomro, & Evangelista, 2021; Alaloul et al., 2022; Khalil & Ashour, 2024 — unverified). The consistency of this advantage across both the interview and survey strands is the strongest triangulated finding in the study.

Cost

Cost findings mirror the literature's central trade-off: high upfront investment (Table 8, item 5.1, WM = 4.74) offset by lower long-term labor, maintenance, and rework costs, consistent with reports that TFS becomes most cost-effective once projects reach the reuse volumes needed to amortize its equipment cost (Ashwin & Paul, 2025). The ₱20–25 million savings case reported in interviews illustrates this pattern at the project level, though — as noted in the Methods — the study did not have access to verified project cost records, so this figure and the survey's cost ratings should be read as practitioner perception rather than audited financial data. This is consistent with, but should not be overstated relative to, reports that traditional formwork can represent 20–25% of total project cost in comparable markets (Varade & Mata, 2024 — unverified).

Safety

Respondents described TFS operations as requiring more procedural control, not less — daily toolbox talks, certified riggers and crane operators, and centralized verification of equipment certification — rather than being inherently safer by design. The lower (though still positive) rating for the general claim that TFS reduces overall risk (4.18) versus the high ratings for specific controls (4.82–4.87) suggests the safety benefit of TFS is best understood as conditional on disciplined implementation, not as an automatic property of the system.

Labor and workforce development

The shift from labor quantity to labor quality is the study's clearest organizational implication. With no formal Philippine certification for TFS operations currently in place, the reliance on internal trade testing described by respondents is a gap the study's recommendations address directly. This finding aligns with the Technology Acceptance Model's emphasis on Perceived Ease of Use: without accessible training pathways, perceived barriers to adoption remain higher than the system's performance advantages alone would predict.

Reusability, sustainability, and site limitations

Steel-formwork reuse reduces both waste and long-term cost, consistent with life-cycle findings that reusable steel formwork's environmental performance improves with cycle count (Balasbaneh et al., 2024 — unverified). At the same time, both the interviews and the literature converge on the same constraint: TFS is optimized for repetitive, regular layouts, and loses efficiency on sloped terrain, irregular floor plans, or buildings that fall short of the reuse volume needed to justify its cost (İlerisoy & Tuna, 2018). This is a genuine limitation rather than an implementation failure, and it argues for site- and project-selection guidance as part of any standardization effort — not for TFS to be treated as a universal replacement for traditional formwork.

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Limitations of the study

Three limitations bear directly on how these findings should be used. First, the sample (n = 41) is drawn from a small population of Philippine TFS practitioners and skews toward early- and mid-career Project Engineers; executive and long-tenure perspectives are essentially absent. Second, cost and savings findings rest on respondent perception and recollection rather than audited project records, which were not available to the study. Third, as flagged throughout this document, a substantial number of the citations supporting the original literature review could not be matched to the reference list and require verification before this becomes a submission-ready manuscript.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. The Tunnel Form System is a viable, high-performing method for Philippine condominium and horizontal housing projects with repetitive structural layouts and large production requirements.
2. Construction speed is TFS's strongest and most consistently corroborated advantage: with adequate coordination, concrete supply, and equipment, it supports rapid daily casting-and-stripping cycles and materially shorter project durations.
3. TFS generates real cost benefits — reduced finishing work, lower labor requirements, less material waste, and long-term formwork reuse — that offset its high initial investment, particularly at scale; these findings are based on practitioner perception rather than verified project accounting, and should be validated with actual cost data in future work.
4. Safety performance improves under TFS specifically when strict protocols, certified operators, and continuous training are maintained; the system introduces its own equipment-related hazard profile that requires dedicated controls rather than eliminating risk outright.
5. TFS shifts labor demand from quantity to quality. The absence of a formal Philippine training or certification track for TFS operations is a concrete gap that standardization efforts should close.
6. TFS is best suited to repetitive structural configurations; its effectiveness declines on irregular geometries and challenging sites (sloping terrain, variable elevation), which argues for project-selection guidance alongside any standardization framework.
7. Taken together, the qualitative and quantitative findings support the case for formal TFS standardization in the Philippines, provided the system's site and scale limitations are addressed explicitly in the resulting guidelines.

Recommendations

Technical standards

Develop unified technical standards for the Tunnel Form System (TFS) covering operational specifications, performance benchmarks, and quality assurance procedures, overseen by a designated standards committee and structured to allow modular updates as equipment and practices evolve. In addition, develop a comprehensive Operational Manual for TFS that provides standardized guidelines for planning, assembly, installation, operation, safety, inspection, maintenance, troubleshooting, and quality control to ensure consistent and efficient implementation across projects.

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Policy

Government agencies should consider formal policy guidance (such as a Department Order) that defines TFS-related roles and responsibilities, designates a lead agency for governance and monitoring, and allocates resources to support adoption within institutional development plans.

Workforce training

Establish a competency-based TFS training program, organized into basic, intermediate, and advanced levels, delivered in partnership with academic institutions and professional bodies, and aligned with (or building on) existing rigger, crane-operator, and welding certifications.

Future research

Priority areas include a life-cycle cost analysis and carbon-footprint assessment of TFS using verified project data (rather than perception-based estimates), performance-based seismic evaluation of tunnel-form buildings under Philippine conditions, comparative studies against other industrialized systems (e.g., aluminum/MIVAN formwork or precast construction), and post-occupancy performance studies of completed TFS structures.

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