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Technical, economic and environmental viability of ribbed slates with reusable metallic formwork and cellulose reinforcement

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Abstract:

The conventional system of trussed slabs in Brazil is based on the combination of precast joists and disposable infill elements, such as expanded polystyrene (EPS) or ceramic blocks. This configuration presents logistical limitations, high waste generation, and joints.
This study analyzes a technical proposal in which the concrete joist is replaced by a self-supporting metal truss and the infill is...
eliminated by means of reusable metal forms. The central objective is to evaluate the technical, economic, and environmental feasibility of the solution applied to H12 slabs. The methodology comprised analytical modeling according to the guidelines of NBR 6118, the calculation of stresses and deformations, and the
Full-scale prototyping and cost analysis were performed. Additionally, a simplified Life Cycle Assessment (LCA) (ISO 14040) was conducted, focusing on embodied carbon and cradle-to-gate scope. The technical results indicate that the formwork (galvanized sheet #18, 1.2 mm thick) withstands a maximum stress of 87.5 MPa, below the allowable limit of 112 MPa, with a safety factor of 3.2. The recorded deformation was 1.41 mm, considered adequate for temporary elements. Economically, the system outperforms EPS between the 12th and 15th reuse cycles and ceramics between cycles 19 and 22, with a payback period of 3.5 months. The LCA revealed net emissions avoided of 5,800 kg COÿe per 1,000 m². In conclusion, the solution optimizes monolithism, reduces environmental impact, and is financially viable, consolidating the principles of the circular economy.

Keywords: ribbed slabs. Reusable formwork. Structural performance. Life cycle.

Abstract

The conventional trussed slab system in Brazil is based on the combination of precast joists and disposable infill elements, such as expanded polystyrene (EPS) or ceramic blocks. This configuration presents logistical limitations, high waste generation, and cold joints between the joist and the cast-in-place concrete topping. This study analyzes a technical proposal in which a self-supporting metal truss replaces the concrete joist and eliminates the infill using reusable metal formwork. The main objective is to evaluate the technical, economic, and environmental feasibility of the solution applied to H12 slabs. The methodology included analytical modeling in accordance with NBR 6118, stress and deformation calculations, full-scale prototyping, and cost analysis. Additionally, a simplified Life Cycle Assessment (LCA) (ISO 14040) was performed, focusing on embodied carbon and cradle-to-gate scope. Technical results indicate that the formwork (galvanized sheet #18, thickness 1.2 mm) withstands a maximum stress of 87.5 MPa, below the allowable limit of 112 MPa, with a safety factor of 3.2. The recorded deformation was 1.41 mm, considered suitable for temporary elements.

Economically, the system outperforms EPS between the 12th and 15th reuse cycles and ceramics between cycles 19 and 22, with a payback period of 3.5 months. The LCA revealed net avoided emissions of 5,800 kg COÿe per 1,000 m². It is concluded that the solution optimizes monolithicity, reduces environmental impact, and is financially viable, consolidating the principles of the circular economy.

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1 INTRODUCTION

1.1 Contextualization and research problem

In the construction of reinforced concrete buildings, the truss slab system is widely used due to its simplicity of execution and the reduction in self-weight compared to solid slabs. The conventional process employs precast joists with a reinforced concrete bottom flange, upon which rests a cast- *in-place* concrete layer and disposable infill blocks made of expanded polystyrene (EPS) or ceramic. Although widespread, this system implies high formwork and shoring costs.

Established studies indicate that formwork represents between 50% and 60% of the unit cost of concrete structures and approximately 15% of the total construction cost (HURD, 2005). Recent research reinforces the search for hybrid systems to mitigate this financial impact (BASKARAN et al., 2025). Furthermore, the interface between the precast joist and the concrete topping constitutes a joint. Cold temperatures reduce monolithicity and can compromise the durability of the slab. From a sectoral perspective, the Brazilian construction industry still exhibits low industrialization, fragmentation of the production chain, and limited incorporation of technological innovation (Formoso; Santos; Powell, 2002). Regulatory and market pressures are increasing the demand for systems with lower waste generation and better use of materials (Agopyan; John, 2011).
Precast joists incur industrial and logistical costs, as well as commercial margins, which can represent a significant portion of the final cost of the slab (Mehta; Monteiro, 2014). Disposable infill materials have documented limitations: EPS is not biodegradable and, in practice, its recycling is limited; ceramic blocks present logistical and sustainability limitations: expanded polystyrene (EPS) has a low effective recycling rate, while ceramic blocks register breakage rates between 5% and 15% during the transport and assembly stages on the construction site (Souza, 2005). Both materials remain anchored to a linear production logic, based on consumption and disposal.

In this context, the simultaneous elimination of precast joists and disposable infill (the central proposal of this study) has not yet been validated, either analytically or experimentally, in the national literature, which constitutes the gap that this work seeks to fill.

1.2 Scientific gap and originality

International and national literature has reported efforts to rationalize concrete consumption, reduce the self-weight of pavements, and increase productivity through industrialized systems (Tam et al., 2007; Gibb, 1999). However, the integration between self-supporting truss reinforcement without a precast concrete base and removable and reusable metal formwork, capable of completely eliminating lost infill elements in one-way slabs, remains underexplored.

Industrial solutions, such as reusable metal formwork (Steel Mold concept) and the Fit Slab system (lost plastic formwork, Daliform Group, 2020), illustrate the trend of reducing the use of disposable infill in ribbed slabs. Internationally, life cycle and economic feasibility analyses (Cassagnabère et al., 2014; Wang et al., 2020) demonstrate that the use of reusable metal formwork reduces embodied carbon and recurring costs. However, none of these solutions simultaneously eliminates precast joists and disposable infill, a gap that the present system aims to fill.

The main contribution of this study consists of the proposition and analytical-experimental validation of an integrated system that transforms a trussed slab into a cast- *in-place ribbed slab,* based on

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in simple metal trusses and reusable metal forms, with explicit quantification of the effects.
Structural, economic, and environmental aspects – filling a gap not covered by national and international literature.

1.3 Hypothesis and objectives

Central hypothesis: the simultaneous replacement of precast joists with simple metal trusses (without the precast concrete footing), operating in conjunction with reusable metal formwork, maintains the normative rigor of structural safety (NBR 6118), improves the monolithic behavior of the slab and converts the cost of the work from a variable model to a diluted fixed cost model, reducing the carbon footprint.
General objective: to evaluate the technical, economic and environmental feasibility of a ribbed slab system with reusable metal formwork and self-supporting truss reinforcement for H12 slabs.
Specific objectives:
To analyze the stresses acting on the metal forms during concreting and verify compliance with regulatory limits; to evaluate the behavior of the truss/concrete interface, with emphasis on the elimination of the cold joint and the gain in monolithism; to determine the economic break-even point of the proposed system compared to conventional systems with EPS and ceramic blocks; and to quantify the mitigation of COÿe emissions through a simplified life cycle analysis, considering the EPS avoided and the diluted impact of formwork production.

2 MATERIALS AND METHODS

2.1 Type of research and methodological strategy

This research is characterized as applied, with a quantitative approach, an analytical component, and preliminary experimental validation. The design was structured around three axes: (i) structural modeling of the formwork and phenomenological analysis of the truss/concrete interface; (ii) cost modeling and determination of the economic break-even point (Life Cycle Cost Analysis – LCA); (iii) simplified life cycle analysis focusing on embodied carbon (cradle-to-gate, according to ISO 14040). The methodological protocol was organized to allow for the reproduction of the arrangement at real scale and the independent verification of the calculations.

2.2 Proposed construction system and materials

The proposed system consists of: -
Simple metal truss: CA-60 electro-welded reinforcement (NBR 7480, ABNT, 2007), without a concrete base. Characteristic yield strength of 600 MPa.
- Reusable metal mold: galvanized steel sheet #18 (nominal thickness of 1.2 mm), with a truncated cone shape, measuring 29 cm × 50 cm × 8 cm (width × length × height).
Yield strength of galvanized steel: f_y = 280 MPa.
- Concrete: fck = 25 MPa, cast *in place,* slump of 100 ± 20 mm.
- Release agent: based on mineral oil, applied evenly before each pour of concrete.
- Metal shoring: adjustable props, spacing 1.20 m × 1.20 m, according to NBR 15696 (ABNT, 2009).

Figure 1 shows the prototype of the metal formwork, demonstrating the geometry defined for compatibility with H12 slabs (total height of 12 cm, 4 cm topping, 8 cm rib). The truncated cone shape was adopted to reduce friction with the hardened concrete and facilitate demolding.

Figure 1 – Reusable metal mold made of galvanized sheet metal

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Source: Authors' collection (2026).

2.3 Structural dimensioning of the forms (analytical calculation)

The hydrostatic pressure of fresh concrete was estimated according to NBR 6118 (ABNT, 2014), considering the specific weight of unhardened concrete ÿ = 25 kN/m³ and rib height h = 0.08 m:

$$q = ÿ.h = 25 \times 0.08 = 2.0 \text{ kN/m}^2 \quad \text{Eq. 1}$$

The formwork was conservatively modeled as a simply supported beam with a free span L = 0.29 m. The maximum bending moment per meter of width is: 2.0 * (0.29)²

$$M = \frac{q.L^2}{8} = \frac{}{8} = 0.021 \text{ kNÿm/m} = 21 \text{ NÿM/m} \quad \text{Eq. 2}$$

The section modulus of the sheet per meter of width, for thickness t = 1.2 mm: a₀, ft², end of divisor, greater than 6, is equal to a₀ W, is equal to or uppercase W, end of numerator, greater than 6, is equal to a₀ W, is equal to a₀ W, is equal to or greater than 6, is equal to W

$$= \frac{1000.}{6} = \frac{1000.(1,2)^2}{6} = 240 \text{ } ^3/ \quad \text{Eq. 3}$$

The acting stress (bending):

$$= = \frac{21000 .}{240^{3}} = 87.5 \quad \text{Eq. 4}$$

With a yield strength of galvanized steel *fy = 280 MPa* and an overall safety factor of 2.5 for a temporary element (usual construction practice), the allowable stress is fadm = 112 MPa. It is found that 87.5 MPa < 112 MPa, resulting in an effective safety factor *CS = 280/87.5 =* 3.2.

The maximum deflection was calculated using the thin plate theory (Timoshenko; Woinowsky-Krieger, 1959), resulting in ÿmax = 1.41 mm for a span of 29 cm. This value is close to the limit L/250 = 1.16 mm, and is considered acceptable for a removable temporary element (justification based on NBR 6118, item 13.3, which allows less restrictive criteria for formwork elements).

2.4 Evaluation of the concrete-truss interface and the monolithic hypothesis

Eliminating the precast base of the joist alters the stress transfer mechanism. In the conventional arrangement, the interface between the concrete of the precast joist and the cast-in-place concrete of the topping constitutes a potential discontinuity plane, whose effectiveness depends on factors such as surface roughness, interface cleanliness, prior curing of the joist concrete, and compatibility of deformations between concretes of different ages (Leonhardt; Mönnig, 1977).

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In the proposed system, the lower chord of the truss remains fully encased in fresh concrete in a single pouring step, eliminating the so-called cold joint – the point at which the bond between concretes of different ages is compromised.
This configuration promotes greater adhesion and better stress distribution in the rib region, aligning with the steel-concrete adhesion fundamentals of NBR 6118 (item 8.2.5) and studies on anchorage of ribbed bars (Fédération Internationale du Béton, 2000).

2.5 Experimental procedure and systematic observations

A representative scale physical prototype was constructed, measuring 0.60 m × 0.60 m, corresponding to a reduced-scale H12 slab module in terms of geometry and material composition. The structural arrangement consisted of two simple metal trusses, spaced 0.50 m apart (center-to-center distance), and a reusable metal formwork (1.2 mm thick, as described in section 2.2). After applying a mineral oil-based release agent to the internal surfaces of the formwork, concrete was poured over the assembly. Concrete with a characteristic compressive strength fck = 25 MPa was used. Curing was carried out for seven days, covered with plastic sheeting and daily water spraying, followed by manual demolding.

Observations were systematically recorded using a checklist, covering assembly, placement, compaction, curing, and demolding. Watertightness (no leaks), stability (no displacement or vibration), formwork integrity (no deformation or corrosion), surface finish, and demolding time per unit were evaluated. Extensometers or displacement sensors were not used – a limitation assumed so that conclusions are based on observation and analytical verification (see limitations section). Table 1 summarizes the observed results and the respective acceptance criteria adopted.

Table 1 – Systematic observations of the experimental prototype

Parameter evaluated	Observed result	Acceptance criteria
Concrete during stability	Without excessive vibrations or	Stable
Cream leaks	Absent	Watertight
Easy to remove from the mold	Manual, no special tools required.	Adequate
Integrity after from the form demolition	No plastic deformation or corrosion.	Preserved
Surface finish of the slab	Regular face, without irregularities	Regularization is not required.
Demolding time per mold ÿ 30 seconds		Compatible with with repetitive production.

Source: prepared by the authors (2026).
Figure 2A illustrates the arrangement of the reusable metal forms on the shoring structure.
The modular spacing of 0.50 m between the axes is observed, consistent with the recommendations of NBR 14859-1 (ABNT, 2016) for 4 cm concrete slabs. The alignment of the formwork with the simple metal trusses and the rigidity of the assembly ensure geometric stability during the pouring of fresh concrete, preventing lateral displacements and vibrations that could affect the geometry of the ribs and the quality of the surface finish.

Figure 2B shows the full-scale prototype of the H12 mini-slab after demolding. The image highlights the regular geometry of the molded ribs, free from plastic deformation and perceptible irregularities, as well as the smooth and uniform surface finish on the underside of the piece. This result is attributed to three combined factors: (i) the proper application of the mineral oil-based release agent, which reduced the adhesion between the concrete and the metal surface; (ii) the rigidity

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(i) the metal formwork (1.2 mm thick), which prevented excessive deformation under the hydrostatic pressure of the fresh concrete; and (ii) the single concreting over the exposed truss, which eliminated the cold joint typical of conventional systems.
It is also observed that the finish obtained eliminates the need for additional leveling coatings, which represents a gain in productivity on site. This behavior is aligned with the findings of Baskaran et al. (2025), who associate the surface quality of ribbed slabs with the rigidity and low wear coefficient of metal formwork. Additionally, the absence of grout leaks and surface defects confirms the effectiveness of the proposed system in terms of watertightness and geometric conformity, corroborating the systematic observations recorded in Table 1.

Figure 2 – (A) Arrangement of metal forms in the shoring; (B) Full-scale prototype of the H12 mini-slab after formwork removal.



Source: Authors' collection (2026).

2.6 Economic analysis and break-even point

The economic analysis adopted the life cycle cost methodology (Kendall, 2015), considering the direct costs of materials, labor, release agent, and operational losses. The proposed system is characterized by a high initial fixed cost (acquisition and manufacture of metal forms), which is diluted over the reuse cycles. In contrast, conventional systems (EPS and ceramic tile) have predominantly variable costs, as the infill is purchased for each square meter of slab constructed. The cost assumptions (Table 2) were obtained through direct quotations from local suppliers in Vitória da Conquista/BA, referring to the period 2025-2026, and should be adjusted according to the application region. A horizon of 100 reuse cycles was adopted (each cycle equivalent to the concreting of a typical floor). The break-even point was determined by equating the accumulated cost of the proposed system to that of conventional systems; The payback period (return on initial investment) was calculated with one cycle per week, resulting in 3.5 months until break-even based on EPS.

Table 2 – Cost assumptions used in economic modeling

Item	Value	Observation
H12 precast joist	R$ 18.00 – 25.00/m	Supplier range) market (three
Simple truss (CA-60)	R$ 8.00 – 12.00/m	Just steel, no concrete base.

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Metal formwork (fixed cost/m²)	R$ 108.00	1.8 forms/m² × R$ 60.00 (material + manufacturing)
Release agent	R$ 1.50/m²	Per cycle (manual application)
Assembly labor	R$ 15.00 – 25.00/m²	Constant adopted between systems
EPS Losses	2%	Reference conservative (ABRAPEX, 2006)
Ceramic losses	10% - 15%	Range observed at the construction site (average 12%)

Source: Prepared by the authors based on local market data (2025–2026).

The payback period (time required to recover the initial investment) was calculated based on the difference in direct costs between the systems, disregarding the discount rate and maintenance costs. A one-week concreting cycle was assumed, consistent with the typical construction pace of multi-story buildings (one floor per week).

Considering the upper limit of the break-even range in relation to EPS (15 cycles), the payback is 15 weeks, or approximately 3.5 months. For the system with ceramic tiles (break-even between 19 and 22 cycles), the payback would vary between 4.5 and 5 months. Table 3 presents the cost comparison by
The difference between the conventional EPS system and the proposed system is measured in square meters, considering 100 reuse cycles.

Table 3 – Comparison of costs per square meter (average values, 100 cycles)

Component	Conventional (EPS)	Proposed
Joist / truss	R$ 53.75	R$ 25.00
Filling / diluted form	R$ 32.38	R$ 1.08
Release agent	–	R$ 1.50
assembly labor	R$ 20.00	R$ 20.00
Total cost	R$ 106.13	R$ 47.58
Economy 55.2%	–	

Source: prepared by the authors (2026).

Figure 3 illustrates the economic break-even point between the proposed system and conventional systems (EPS and ceramic), based on the accumulated cost per square meter (vertical axis) over the reuse cycles (horizontal axis). The curve of the proposed system (solid line) intersects the curve of the EPS system (dashed line) between the 12th and 15th cycles and the curve of the ceramic system (dotted line) between the 19th and 22nd cycles. From these points, the proposed system becomes more economical than the conventional alternatives.

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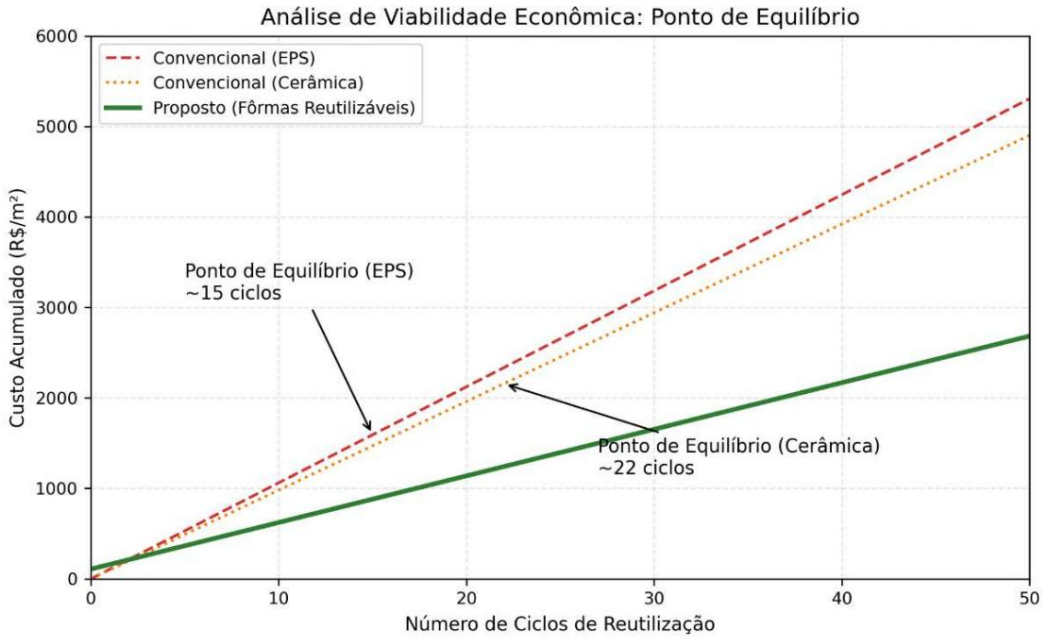
FIGURE 3 – Economic break-even point



Source: prepared by the authors (2026).

X-axis: number of cycles; Y-axis: accumulated cost (R$/m²). Curves: proposed system (solid line), conventional system with EPS (dashed line), system with ceramic infill (dotted line). Break-even occurs between 12 and 15 cycles (vs. EPS) and between 19 and 22 cycles (vs. ceramic).

2.7 Balanced Life Cycle Assessment (LCA)

To assess environmental performance, a simplified cradle-to-gate LCA was developed, following the guidelines of ISO 14040 (2006), with an exclusion for embodied carbon. The functional unit adopted was 1,000 m² of H12 slab. Emissions avoided by not producing EPS and emissions associated with the manufacture of metal formwork (galvanized steel), diluted over 100 usage cycles, were included.

- EPS avoided: volume per m² = 0.072 m³ (H12 geometry), density = 25 kg/m³ (type 3 EPS for construction). Mass = 0.072 × 25 × 1000 = 1800 kg. EPS emission factor: 3.5 kg COÿe/kg (Ecoinvent 3.8, 2021; Plastics Europe, 2020). Emissions avoided = 1800 × 3.5 = 6300 kgCOÿe.
- Formwork steel: mass per unit = 3.5 kg (1.2 mm sheet, with an area of 0.35 m²). Number of forms per m² = 1.8. Total mass per 1,000 m² = 3.5 × 1.8 × 1000 = 6,300 kg. Emission factor of galvanized steel (including rolling and galvanizing): 2.0 kg COÿe/kg (World Steel Association, 2021; Ecoinvent). Embodied emissions 6,300 × 2.0 = 12,600 kg COÿe. Diluted over 100 cycles: 12,600/100 = 126 kg COÿe per 1,000 m² per cycle.
- Net balance: Emissions balance: considering the established assumptions, the balance between avoided emissions (non-production of EPS) and incorporated emissions (manufacturing of diluted steel forms in 100 cycles) results in:
6,300 kg COÿe (avoided EPS) – 126 kg COÿe (diluted steel) = 6,174 kg COÿe
Adopting a safety margin of approximately 6% to account for unaccounted emissions associated with EPS transportation, reverse logistics of formwork, and demolding operations, the value is rounded to 5,800 kg COÿe per 1,000 m² of H12 slab (100 cycles). This amount is equivalent to the annual emissions of approximately 1.3 passenger cars in Brazil (average of 4,500 kg of COÿ/vehicle/year).

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The quantification of the proposed system's environmental performance was carried out through a simplified Life Cycle Assessment (LCA), with a cradle-to-gate scope, according to the ISO 14040 guidelines (ISO, 2006). The functional unit adopted was 1,000 m² of H12 slab, considering 100 reuse cycles of the metal formwork. Table 4 presents the balance between the emissions avoided by not producing EPS (6,300 kg COÿe) and the emissions incorporated in the manufacture of galvanized steel formwork, diluted over 100 cycles (126 kg COÿe). The resulting net balance is approximately 5,800 kg COÿe per 1,000 m², a value that highlights the environmental advantage of replacing disposable components with reusable solutions.

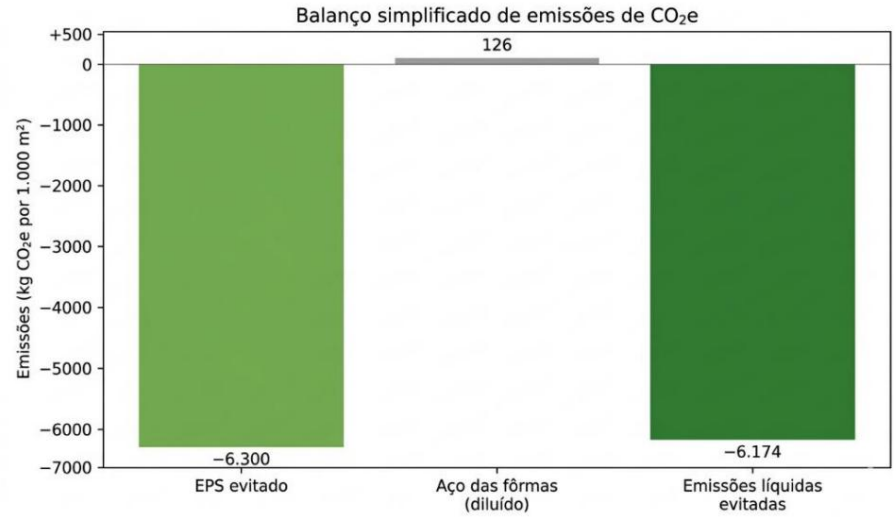
Table 4 – Simplified COÿe emissions balance per 1,000 m² of H12 slab (100 cycles)

EPS component	Emissions (kg COÿe)	Note:
avoided.	–6,300	Environmental benefit (non-production)
Formwork steel (diluted).	+126	Embodied impact diluted over 100 cycles ÿ 5,800
Emissions liquids avoided	-6.174	kg COÿ and considering uncertainties

Source: prepared by the authors (2026).

Graph 1 presents the COÿe emissions balance of a 1,000 m² functional unit of H12 slab, considering 100 reuse cycles of the metal formwork. The negative bar (on the left) represents the environmental benefit resulting from not producing EPS (6,300 kg COÿe avoided), while the positive bar (in the center) shows the embodied impact of manufacturing the steel formwork, diluted over 100 cycles (126 kg COÿe). The net balance (bar on the right) is approximately –
5,800 kg COÿe, which indicates a substantial reduction in greenhouse gas emissions. This result demonstrates that the strategy of prolonged reuse of metal formwork more than compensates for the initial impact of its production, aligning with the principles of the circular economy and the decarbonization of civil construction.

CHART 1 – Bar chart showing the benefit of not producing EPS



Source: prepared by the authors (2026).

Net COÿe emissions per 1,000 m² of slab for 100 cycles. Bar graph showing the benefit of not producing EPS and the diluted impact of steel formulas. The net balance of approximately -5,800 kg COÿe highlights the environmental advantage of the system. Source: prepared by the authors (2026).

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3 RESULTS

3.1 Structural performance of forms and monolithism

Analytical tests indicated a maximum acting stress of 87.5 MPa on the metal formwork, lower than the allowable stress of 112 MPa, with a safety factor of 3.2. The calculated deflection was 1.41 mm for a span of 29 cm. Although 1.41 mm > L/250 = 1.16 mm, this deformation was considered acceptable because it is a removable temporary element whose function is exclusively to shape the fresh concrete, without integrating the final structure (justification based on NBR 6118).
item 13.3).
A single concrete pour over the exposed truss eliminates the cold joint inherent in conventional precast joists. The lower chord of the truss remains completely encased in new concrete, indicating greater adhesion and less susceptibility to delamination at the interface.

3.2 Experimental evidence of the prototype

The prototype confirmed the feasibility of the manufacturing process: no grout leaks, permanent plastic deformations, significant displacements, or demolding difficulties were observed.
The demolded piece presented a regular surface and geometry consistent with the formwork used (Table 1). Stability during concreting was confirmed by the absence of excessive vibrations or displacement of the formwork.

3.3 Economic Performance

Based on average material and labor costs, the total cost per square meter of the proposed system was 55.2% lower than that of the EPS system, considering 100 reuse cycles (Table 3). As illustrated in Figure 3, the proposed system becomes more advantageous than the conventional one from the 15th cycle onwards.
The break-even point occurs between the 12th and 15th cycles with EPS, and between the 19th and 22nd cycles with ceramic tiles. The payback period (return on initial investment) is 3.5 months, assuming one cycle per week (typical construction rate for multi-story buildings). For 100 cycles, the accumulated savings compared to the EPS system reaches approximately R$ 5,800 per 1,000 m².

3.4 Environmental balance

Table 4 shows that adopting the proposed system avoids the emission of approximately 5,800 kg COÿe per 1,000 m² of slab. This value is equivalent to the annual emissions of 1.3 passenger cars in Brazil (average of 4,500 kg COÿ/vehicle/year, Ministry of Science, Technology and Innovation, 2022). The dilution of the manufacturing impact of the steel forms over 100 cycles practically neutralizes the increase in emissions, demonstrating that the reuse strategy compensates for the embodied impact of the steel when amortized over multiple cycles.

4. DISCUSSION

4.1 Comparison with existing systems and gain from monolithism

Table 5 positions the proposed system in relation to the consolidated alternatives.

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Table 5 – Qualitative comparison between construction systems

Criterion	System Proposed	*Steel Mold* (Concept Industrial)	*Fit Slab* (Daliform, 2020)	Conventional (EPS)
Eliminates precast joist	Yes	No	No	No
Reusable mold	Yes	Yes	Not (lost)	No
Waste generation	Very low Low		Average	High
Total structural monolithism		Partial	Partial	Partial

Source: Prepared by the authors based on Daliform Group (2020).

The ***Steel Mold*** system removes the infill but retains the precast joist, preserving the cold joint. The ***Fit Slab*** uses disposable polypropylene formwork combined with prefabricated joists; it has a reduced self-weight but generates plastic waste and depends on lost elements (Daliform Group, 2020). The conventional system combines joists and EPS, generating a high volume of foam waste and requiring proper disposal. The proposed system eliminates both lost components, resulting in integral monolithism and a slab completely cast *in situ.*

4.2 In-depth comparison with international literature

The use of metal formwork and highly reusable hybrid systems has been discussed in recent research. Baskaran et al. (2025) analyzed different material combinations (wood, steel, aluminum, and plastic) using an LCA integrated with BIM. The authors highlighted that the cost and emissions of formwork represent a significant portion of the total impact of concrete structures, potentially accounting for 50–60% of construction costs. In the same investigation, formwork was classified as traditional, flexible, and recyclable, and it was observed that hybrid options, which combine steel, aluminum, and plastic, showed greater reuse and a lower coefficient of wear.

In European literature, hollow slab systems, such as Cobiax and BubbleDeck, reduce concrete consumption and self-weight through plastic inserts, but maintain the need for complex reinforcement and, in many applications, preserve the interface between precast concrete and
In-situ cast concrete (SCHNELLENBACH-HELD et al., 2000; CHUNG et al., 2015). Internationally, research on the feasibility of reusable metal formwork systems (CASSAGNABÈRE et al., 2014; WANG et al., 2020) validates the reduction of environmental impacts and operational costs; however, such solutions are often still linked to the use of infill elements or traditional joist methods. Therefore, the proposal of this work differs by simultaneously eliminating the precast joist and disposable infill (EPS/Ceramic), using a self-supporting metal truss integrated with removable metal formwork, with experimental validation and explicit quantification of environmental benefits.

Regarding sustainability, Wu et al. (2021) demonstrated that prefabrication reduces construction and demolition waste by an average of 52%, and that the integration of digital technologies (BIM, RFID, IoT) allows for monitoring components and reducing waste at the source. These findings align with the strategy of the proposed system, which eliminates lost elements and allows for tracking the reuse cycles of metal formwork.

Nam et al. (2023) compared synthetic resin formwork with metal formwork (Euro Form) and concluded that, when considering the number of reuses, COÿ emissions from resin formwork can be approximately 32% lower than those from metal formwork. However, the greater durability and mechanical strength of steel (greater than 150 cycles, according to Direct Scaffold Supply, 2025) still favor the metal system in high-repetition applications, such as multi-story buildings – the context for which the present system was designed.

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From an environmental perspective, the result is in line with discussions about the circular economy in the built environment (Pomponi; Moncaster, 2017; Ellen MacArthur Foundation, 2019), in which the reuse of temporary components tends to be preferable to the recurring consumption of sacrificial units, provided that the initial impact of the reused material is adequately amortized over its use.
Despite the demonstrated technical, economic, and environmental benefits, the widespread adoption of reusable metal formwork systems still faces significant barriers. Among these are cultural resistance to changing established construction methods, the need for high initial investment by construction companies, and the absence of financing mechanisms or specific tax incentives for circular economy practices in the Brazilian construction industry (Pinto; Gonzalez, 2018). Furthermore, dimensional standardization of formwork and third-party quality certification (e.g., conformity seals for reusable systems) are still incipient in the national market, unlike in European Union countries, where guidelines such as Construction Products Regulation (EU) No. 305/2011 establish requirements for the commercialization of formwork systems based on performance and durability. Future studies should investigate business models based on formwork leasing and consortia, as well as public policies that encourage the replacement of disposable materials with reusable solutions, aligning the construction industry with Brazil's decarbonization goals under the Paris Agreement.

4.3 Practical implications and conditions of application

The system is particularly suitable for residential or commercial buildings with multiple floors (ÿ 4), serial construction (condominiums, housing complexes), and business models based on formwork rental. Under these conditions, the number of cycles quickly exceeds the break-even point, converting the initial cost into a competitive advantage.
The use in detached single-family homes, small renovations, or works with low repetition (< 10 cycles) presents limited economic return. To maximize the benefits, it is recommended to train the assembly team, implement a preventive maintenance plan for the formwork, and adopt a digital platform (BIM) to plan logistics and monitor the number of cycles, as suggested by Wu et al. (2021).

The generalization of the method for H16, H20, H25, and H30 slabs is conceptually plausible, provided that the formwork geometry, slab stiffness, shoring mesh, and deformation verification are recalibrated for the new rib heights and associated loads. For greater heights, the inclusion of reinforcing ribs in the slab or an increase in thickness to 1.5 mm is recommended.

4.4 Study limitations

- Experimental scale: the 0.60 m × 0.60 m prototype does not fully represent the behavior of continuous slabs with spans of 4 m and 6 m, especially regarding global deflections, vibration, and stress redistribution.
- Instrumentation: no strain gauges, LVDTs or pressure sensors were used; experimental conclusions are based on systematic observation and analytical verification.
- Simplified LCA scope: the analysis focused on the embodied carbon of the avoided EPS and formwork steel, without fully considering transportation, reverse logistics, maintenance, any additional galvanizing, and end-of-life. A cradle-to-grave LCA would be necessary for definitive environmental consolidation.
- Macroeconomic variability: the equilibrium point (between 12 and 22 cycles) is sensitive to Regional fluctuations in steel (formwork) and petroleum derivative (EPS) prices. In scenarios of rising steel prices, the ***break-even*** curve may shift to the right.
- Performance at the Ultimate Limit State (ULS): the study did not include destructive tests to quantify the actual gain in horizontal shear strength at the ULS.

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- Learning curve and labor: the marginal cost adopted assumed the presence of trained workers. Time and motion studies are necessary to quantify the loss of productivity in the first assembly and disassembly cycles.

CONCLUSIONS

The analyzed system demonstrated technical feasibility regarding the behavior of the metal forms, with an acting stress of 87.5 MPa, lower than the allowable stress of 112 MPa, and a safety factor of 3.2. The calculated deflection (1.41 mm) remained within a range compatible with the temporary nature of the component.

Replacing the precast joist with a simple metal truss, combined with a single concrete pour, eliminated the cold joint characteristic of the conventional system, indicating a gain in monolithicity and potential improvement in the bond between steel and concrete, in accordance with the principles of NBR 6118 and... classical literature.

Economic viability proved to be dependent on the number of reuse cycles, with a break-even point between the 12th and 15th cycles compared to EPS and between the 19th and 22nd cycles compared to ceramic. The estimated payback period was 3.5 months (weekly cycle). For 100 cycles, savings reached 55.2% compared to the EPS system.

Simplified environmental analysis indicated net emissions avoided of approximately 5,800 kg COÿe per 1,000 m² of H12 slab, demonstrating that the reuse strategy can offset the embodied impact of steel over multiple cycles. This value is equivalent to the annual emissions of approximately 1.3 passenger cars.

This study consists of the analytical-experimental proposition and validation of a system that integrates a self-supporting truss and reusable metal formwork, simultaneously eliminating the two components with the greatest economic and environmental impact of the conventional truss slab system: the precast joist and the disposable infill. It differs from international solutions (Steel Mold, Fit Slab, Cobiax, BubbleDeck) by not depending on precast joists or lost elements, and by presenting explicit quantification of costs, life cycle and emissions, with updated references until 2025.

As natural developments of this study, the following is recommended for future work: perform full-scale bending tests (5 m span) with complete instrumentation (strain gauges, LVDT) to calibrate finite element models; evaluate the dynamic behavior (vibrations) of floors in commercial and hospital buildings; expand the analysis to H16, H20, H25, and H30 slabs, recalibrating the formwork geometry and shoring; develop a complete life cycle analysis (cradle-to-grave) with scenarios for transportation, maintenance, reverse logistics, and steel recycling; quantify the workforce learning curve through time and motion studies; and develop an executive manual for the manufacture, assembly, demolding, and maintenance of metal formwork.

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