Community-Oriented Planning and Preliminary Structural Analysis of a Modular Bamboo Bridge in Purwosari Village

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Abstract

Limited crossing access between agricultural plots and distribution routes is a practical problem for the Timun Mas Farmers Group in Purwosari Village, Wonogiri Regency, Indonesia. This article reports the preliminary planning and engineering-analysis phase of a community-oriented modular bamboo bridge initiative rather than a completed bridge implementation. The current stage used project drawings and site documentation to define an 8 m Cremona truss span within a 13 m overall bridge arrangement, followed by two-dimensional nodal-equilibrium analysis, elastic frame verification, and load-sensitivity screening. A preliminary service-load scenario of 5.5 kPa (5.0 kPa live load plus a 0.5 kPa deck/dead-load allowance) produced support reactions of 19.80 kN at each support, a global bending moment of 39.60 kNm per truss plane, maximum lower-chord tension of 19.80 kN, maximum upper-chord compression of 19.56 kN, maximum diagonal compression of 22.91 kN, and an estimated mid-span deflection of 10.64 mm. The analysis indicates that the proposed truss transfers global bending primarily through axial chord forces, while diagonal compression and joint capacity remain critical design considerations. At the stage reported here, fabrication, bridge erection, participant training, static load testing, and before-and-after community-outcome evaluation had not yet been completed; therefore, reductions in travel time, transport cost, and distribution delays are treated as future evaluation indicators rather than measured outcomes. These results provide a technical basis for subsequent community-service stages, including bamboo material characterization, connection verification, final structural modelling, controlled load testing, participatory installation, training, and partner evaluation.

Keywords: *modular bamboo bridge; community planning; Cremona truss; rural accessibility; preliminary structural analysis.*

Introduction

Geographically, Purwosari Village features undulating terrain at an elevation of approximately 266 m above sea level. The majority of the local population relies on agriculture as a primary livelihood. Agricultural land consists of rain-fed paddy fields and dryland areas that are predominantly cultivated with rice and secondary crops (palawija), such as cassava, peanuts, and maize. Administratively, Purwosari is one of the villages within Wonogiri District and is located approximately 5 km northeast of the district urban center. The village covers approximately 507.42 ha, including wetland/paddy fields, dry fields, residential yards, and other land-use categories.

Figure 1.
Map of Purwosari Village, Wonogiri



The Timun Mas Farmers Group is a productive agricultural cooperative located in Purwosari Village, Wonogiri Regency, whose members primarily rely on horticultural cultivation and dryland farming for their livelihoods. Purwosari Village possesses significant agrarian potential, supported by the availability of smallholder agricultural land and a local workforce. However, the village's geographical landscape—intersected by river channels and irrigation canals—restricts accessibility between agricultural plots, as well as between production fields and main distribution routes, particularly during the rainy season. This infrastructural constraint in crossing points directly hinders the efficiency of agricultural production and distribution activities for the partner farmers.

Connectivity infrastructure in rural areas is an important component of agricultural production and distribution systems because roads and crossing points influence the movement of production inputs, labor, and harvested products. In Wonogiri Regency, previous village-infrastructure assessment has also highlighted the importance of aligning infrastructure planning and local technical capacity with village development conditions (Ristanto et al., 2024). For Purwosari Village, the immediate concern is the reliability of crossing access between agricultural plots and the routes used to move agricultural products.

Research on bamboo bridges indicates that structural analysis must account for truss configuration, material properties, load transfer, connection details, and preservation processes. Quintero et al. (2022) analyzed a Guadua bamboo truss bridge using finite-element software and emphasized the importance of detailed structural modelling, mechanical properties, load-transfer mechanisms, joint connections, and material treatment. An Indonesian bamboo bridge case study likewise demonstrates the importance of translating structural concepts into buildable detailing (Raposo & Moura, 2023), while research on bamboo bridge stiffening shows that bracing arrangements can affect structural response (Ghudawat, 2024). More generally, modular bridge configuration influences stiffness and load-carrying behavior (Embaby & El Naggar, 2025). Consequently, conceptual drawings alone are insufficient for a design intended to progress toward safe practical adoption.

The present initiative responds to this local access problem by developing a modular bamboo bridge concept for the Timun Mas Farmers Group. At the stage reported in this article, the work is limited to preliminary planning and structural analysis; bridge fabrication, installation, and community-outcome evaluation are subsequent stages. Potential benefits for agricultural

distribution are therefore treated as hypotheses to be evaluated after the bridge has been constructed, tested, and used, rather than as outcomes already achieved.

Figure 2.
Research location for the bridge project in Purwosari Village, Wonogiri.



When river or ditch crossing access is disrupted, particularly during rainy conditions, movement between agricultural plots and distribution routes may become less direct and less reliable. For this project, the potential community benefits are operationalized as indicators to be measured after implementation: travel time per trip, transportation cost per trip or per unit of produce, distribution frequency, access to collectors or markets, safety perceptions, the volume of produce transported per trip, the number of trips per week, and changes in post-harvest losses where feasible. These variables are evaluation targets for the later community-service phase and are not presented as measured outcomes of the preliminary engineering stage reported here.

Materials and Methods

Scope, Community Partner, and Study Design

This study reports the preliminary engineering and planning phase of a community-oriented bridge project for the Timun Mas Farmers Group in Purwosari Village, Wonogiri Regency. The manuscript does not treat the bridge as a completed community intervention. The scope reported here comprises identification of the access problem from available project and site documentation, interpretation of the bridge drawings, preliminary truss analysis, elastic frame verification, and load-sensitivity screening. Fabrication, erection, safe-use training, operation and maintenance training, static load testing, and before-and-after community evaluation are subsequent stages and are not presented as completed outcomes in this article. Because no participant-based community intervention was undertaken in the analytical phase reported here, an implementation period and participant count are not applicable to these preliminary results. Accordingly, no participant-based training results or measured changes in travel time, transport cost, distribution frequency, or farmer income are claimed at this stage. The engineering workflow uses deterministic static equilibrium and elastic verification, while the broader community-service roadmap is retained only to show how the technical analysis informs later implementation. The next phases described in the project plan include material characterization, final modelling, fabrication, controlled load testing, participatory installation, training, and impact evaluation (Devi et al., 2026).

The bridge is idealized as a truss-based structural system. In the first-stage analysis, the principal truss members are assumed to transfer axial forces through pin-type joints. This assumption is consistent with the fundamental concept of the Cremona graphical method, in which each joint is analyzed using static equilibrium.

The global equilibrium conditions are:

$$\sum Fx = 0$$

$$\sum Fy = 0$$

$$\sum M = 0$$

For a symmetric simply supported bridge subjected to a symmetric vertical load, the vertical support reactions can initially be expressed as:

$$RA = RB = \frac{W}{2}$$

where:

R_A= vertical reaction at support A,

R_B= vertical reaction at support B,

W= total applied vertical load.

For an unsymmetrical loading condition:

$$\boldsymbol{R_A + R_B = W}$$

and the individual reactions are determined from moment equilibrium.

Structural Materials and Analytical Geometry

The proposed bridge structure uses preserved structural bamboo culms with diameters ranging from 8 to 10 cm, M12-M16 bolts, nuts, and washers, 6-mm-thick steel connection plates, and bamboo deck boards. These components support a modular structural system in which the bamboo culms function as the primary load-bearing members and bolted steel plates provide mechanical connections between structural elements. The use of round bamboo as a structural material is consistent with ISO 22156:2021, but actual member resistance and serviceability must be verified using experimentally determined material properties (International Organization for Standardization [ISO], 2021). Connection behavior is particularly important in bamboo structures; complete joint testing and explicit verification of joint capacity have been emphasized in experimental work on bamboo connections (Harries et al., 2022).

For the preliminary numerical analysis, the actual diameter and wall thickness of each bamboo culm were not yet available from direct material measurements. Therefore, a representative cross-section with an outer diameter (D) of 90 mm and a wall thickness (t) of 10 mm was adopted for the analytical model. These values are not experimental material-test results, but rather modelling assumptions used to establish the initial structural model. Consequently, they must be replaced by the actual geometric and mechanical properties obtained from the characterization of the bamboo culms used in the prototype before the numerical results are used for final structural design. This approach is particularly important because bamboo exhibits variability in its physical and mechanical properties, and structural design should preferably employ experimentally determined characteristic values (ISO, 2021).

Table 1.
Geometric Parameters Used in the Analytical Model

Parameter	Value	Basis of Determination
Total bridge length	13.0 m	Interpreted from the side and top views of the design drawings
Deck length	10.0 m	Interpreted from the top view of the design drawing
Deck width	1.8 m	Interpreted from the top view of the design drawing
Main truss span	8.0 m	Based on the 800 dimension shown in the side view
Maximum truss height	2.0 m	Based on the vertical 200 dimension shown in the side view

Truss panels	8 panels × 1.0 m	Idealized from the truss configuration shown in the design drawing
Number of truss planes	2 planes	Assumed to be symmetrical on the left and right sides

The analytical geometry was established by interpreting the dimensions and structural configuration shown in the bridge design drawings. The 13.0-m total bridge length includes the overall structural arrangement, while the 10.0-m deck length represents the effective length of the deck. The bridge has a 1.8-m deck width, an 8.0-m main truss span, and an approximately 2.0-m maximum truss height. The main truss was idealized into eight panels, each approximately 1.0 m long. Two longitudinal truss planes were assumed to provide a symmetrical structural configuration. This idealization was adopted to facilitate the preliminary two-dimensional structural analysis and subsequent numerical verification.

Determinacy of the Analytical Truss Model

The two-dimensional analytical model consists of 18 joints and 33 members with three support reactions, satisfying the relationship m = 2j - r for a statically determinate truss under the idealized pin-jointed condition. Actual bolted-plate connections may, however, provide some rotational stiffness. A frame model is therefore used as an additional verification model to examine secondary bending moments and structural deflection. This complementary modelling approach is important because the behavior of a bamboo bridge can depart from an idealized pin-jointed truss as a result of connection stiffness and load-transfer characteristics (Quintero et al., 2022; Harries et al., 2022).

Table 2.
Material and Cross-Sectional Parameters Used in the Preliminary Analysis

Parameter	Value	Description
Outer bamboo diameter	90 mm	Initial assumption based on the Ø8–10 cm range specified in the research proposal
Wall thickness	10 mm	Numerical assumption; to be replaced with actual characterization results
Elastic modulus, (E)	10 GPa	Initial numerical assumption
Cross-sectional area, (A)	±2,513 mm^2	Calculated for a hollow circular section with (D=90) mm and (t=10) mm
Second moment of area, (I)	±2.04 × 10^6 mm^4	Calculated for a hollow circular section with (D=90) mm and (t=10) mm

Preserved structural bamboo culms with diameters ranging from 8 to 10 cm, bamboo deck boards, M12–M16 bolts, nuts, and washers, and 6-mm-thick steel connection plates. The representative cross-section of (D=90) mm and (t=10) mm and the assumed elastic modulus of (E=10) GPa are used exclusively as **preliminary modelling parameters**. They should not be interpreted as experimentally determined material properties.

This distinction is important because bamboo exhibits natural variability in its geometric and mechanical characteristics. ISO 22156:2021 emphasizes the use of experimentally determined characteristic values of bamboo strength and stiffness in structural design and recognizes documented design-by-testing approaches (ISO, 2021). Accordingly, the numerical model presented here should subsequently be updated using the actual diameter, wall thickness, moisture condition, density, and mechanical properties of the bamboo culms selected for the prototype. This calibration is necessary before the model can be used for final structural verification.

Preliminary Engineering Results and Community Implementation Plan

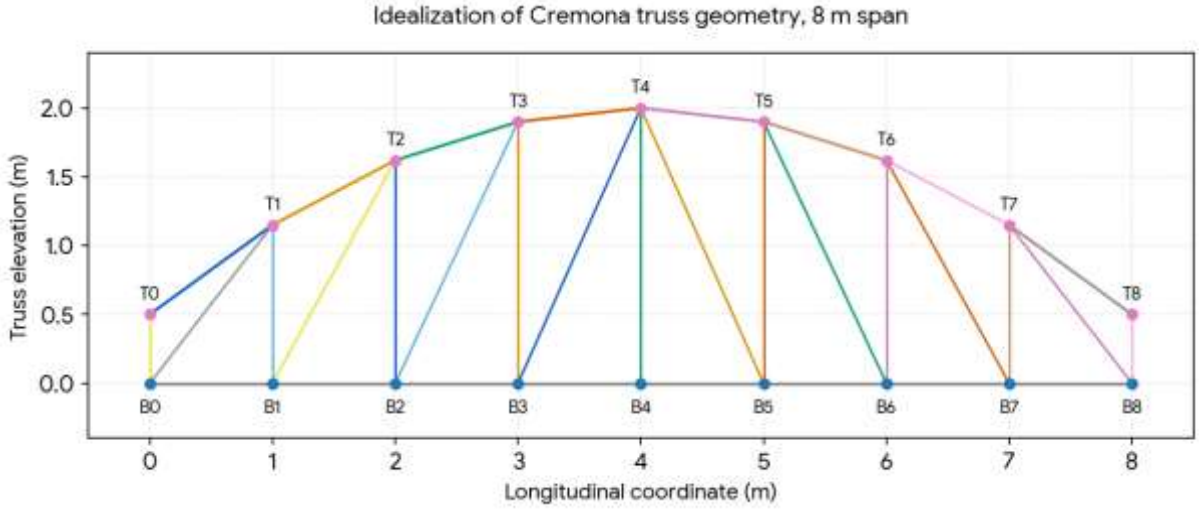
Structural Analysis

Table 3.
Summary of Structural Analysis Results

Parameter	Result	Basis of Analysis
Total applied load	5.5 kPa	Preliminary numerical scenario
Load per truss plane	4.95 kN/m	q × deck width / 2
Left support reaction	19.80 kN	Static equilibrium
Right support reaction	19.80 kN	Static equilibrium
Equivalent global bending moment	39.60 kNm	(wL^2/8)
Maximum lower-chord force	19.80 kN	Tension
Maximum upper-chord force	19.56 kN	Compression
Maximum diagonal force	22.91 kN	Compression
Midspan frame deflection	10.64 mm	Elastic frame verification
Maximum local bending moment	0.313 kNm	Elastic frame model

The preliminary analysis demonstrates behavior consistent with a truss system. The global moment is not resisted entirely as bending within a single member; instead, it is transformed into a couple of axial forces along the chords. The lower chord experiences predominant tension with a maximum force of approximately 19.80 kN, whereas the upper chord undergoes compression of approximately 19.56 kN. The diagonal members adjacent to the supports are the most critical compressive elements, with a maximum force of approximately 22.91 kN. These findings identify joint connection capacity and compressive-member stability as priorities for the next design and testing stages.

Figure 3.
Geometric idealization of the truss for two-dimensional analysis.

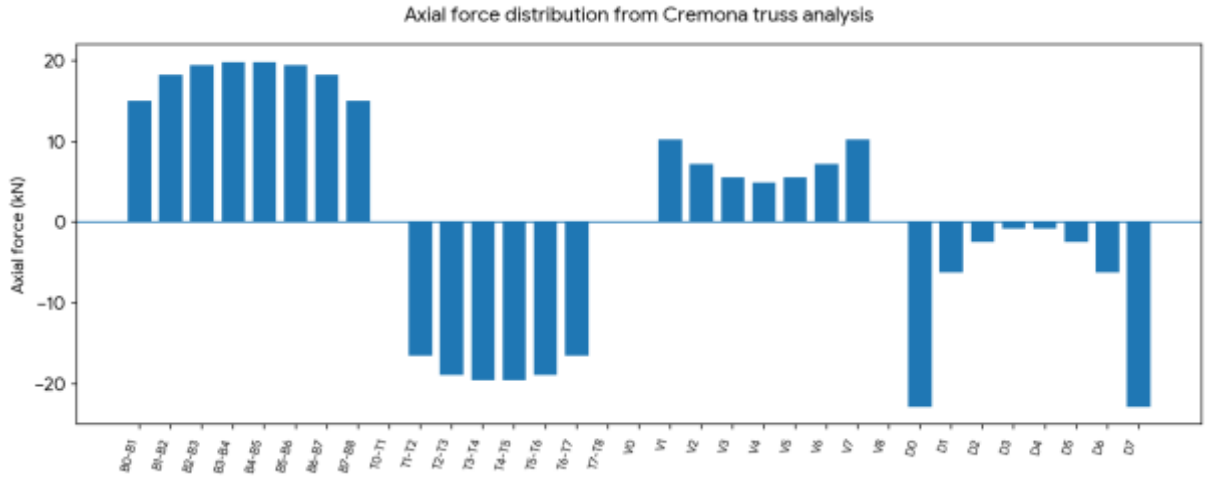


The Cremona method is implemented as a two-dimensional nodal equilibrium. The conditions $\Sigma Fx = 0$ and $\Sigma Fy = 0$ apply at each node. A positive sign indicates tension, while a negative sign indicates compression. The following results represent the axial forces in each element.

Table 4.
Results of Axial Force Analysis Using the Cremona Method

Element	Length (m)	Axial force (kN)	Action
B0-B1	1.000	14.984	Tension
B1-B2	1.000	18.277	Tension
B2-B3	1.000	19.475	Tension
B3-B4	1.000	19.800	Tension
B4-B5	1.000	19.800	Tension
B5-B6	1.000	19.475	Tension
B6-B7	1.000	18.277	Tension
B7-B8	1.000	14.984	Tension
T0-T1	1.196	-0.000	≈0
T1-T2	1.104	-16.548	Compression
T2-T3	1.039	-18.986	Compression
T3-T4	1.004	-19.561	Compression
T4-T5	1.004	-19.561	Compression
T5-T6	1.039	-18.986	Compression
T6-T7	1.104	-16.548	Compression
T7-T8	1.196	0.000	≈0
V0	0.500	-0.000	≈0
V1	1.156	10.301	Tension
V2	1.625	7.235	Tension
V3	1.906	5.599	Tension
V4	2.000	4.950	Tension
V5	1.906	5.599	Tension
V6	1.625	7.235	Tension
V7	1.156	10.301	Tension
V8	0.500	0.000	≈0
D0	1.529	-22.906	Compression
D1	1.908	-6.283	Compression
D2	2.153	-2.580	Compression
D3	2.236	-0.726	Compression
D4	2.236	-0.726	Compression
D5	2.153	-2.580	Compression
D6	1.908	-6.283	Compression
D7	1.529	-22.906	Compression

Figure 4.
Axial force distribution from the Cremona analysis.



The results indicate that the bottom chord is subjected primarily to tension, with a maximum value of 19.80 kN at mid-span, whereas the top chord is subjected to compression, with a maximum value of approximately 19.56 kN. The diagonal member near the support is the most critical compression element, carrying a force of approximately 22.91 kN. The vertical member experiences a maximum tensile force of approximately 10.30 kN. This pattern is consistent with truss behavior: support reactions are transferred via the diagonals to the chords, while the global bending moment is converted into a tension-compression force couple within the chords.

Load sensitivity

The 9.5 kPa scenario is used solely for response screening. This value must not be treated as evidence that the bridge meets a specific vehicle traffic class because the design vehicle, load factors, load combinations, final connection capacities, and material test results have not yet been established. The final structural model must be checked against the intended use agreed with the partner and the applicable bridge-loading provisions (Badan Standardisasi Nasional [BSN], 2016).

Table 5.
Sensitivity of the structural response to increased loading.

Scenario	Total q (kPa)	Line load per truss (kN/m)	Global M (kNm)	Mid-span δ (mm)	Max. local M (kNm)
Initial scenario	5.5	4.95	39.60	10.64	0.313
Higher screening	9.5	8.55	68.40	18.38	0.540

Planned Community-Service Outputs and Evaluation Indicators

The community-service phase is planned around four linked areas: crossing access, safe use, maintenance governance, and benefit evaluation. Table 5 presents the intended activities, success indicators, and expected benefits. These entries are implementation targets rather than measured results; at the stage reported here, a functional bridge, participant training outcomes, maintenance performance, transport-cost reductions, and distribution improvements have not yet been verified.

Table 6.
Planned community-service outputs and evaluation indicators

Dimension	Planned activity/output	Proposed success indicator	Intended benefit
Crossing access	Modular bamboo Cremona truss bridge	1 functional bridge unit	Access for farmers and transport
Safety	Safe usage training	≥80% of participants understand function/maintenance	Safer usage
Maintenance	Usage & maintenance SOPs	SOPs available and understood	Asset can be managed
Logistics costs	Cost calculation assistance	Transport costs lower than baseline	Business efficiency
Distribution	Physical access improvements	More timely shipments	Smoother downstream operations

Frame-Model Moments and Deflections

The maximum local moment in the elastic frame model is approximately 0.313 kNm in the vertical member near the end of the span, and the maximum vertical deflection at mid-span is approximately 10.64 mm. As a sensitivity check, increasing the total load to 9.5 kPa (9.0 kPa screening live load plus a 0.5 kPa allowance) increases the equivalent global moment to approximately 68.40 kNm and the mid-span frame deflection to approximately 18.38 mm. This higher-load scenario is used only to examine response sensitivity and should not be interpreted as evidence of compliance with all SNI requirements for vehicular bridges (BSN, 2016).

Table 7.
Sensitivity of structural response to load increase.

Scenario	Total q (kPa)	Line load per truss (kN/m)	Global M (kNm)	Mid-span δ (mm)	Max. local M (kNm)
Main	5.0 + 0.5	4.95	39.60	10.64	0.313
Sensitivity	9.0 + 0.5	8.55	68.40	18.38	0.540

Discussion

The main technical contribution of the preliminary design is the use of a truss configuration to convert global bending response into axial forces. The calculated global moment of 39.60 kNm and chord force of approximately 19.80 kN illustrate the mechanical relationship between truss height and force transfer. Increasing effective truss height can reduce chord forces for a given global moment, but it also increases spatial requirements, diagonal lengths, member-stability demands, and connection complexity. Geometric optimization should therefore consider the structural system as a whole rather than simply maximizing truss height. Modular-bridge research similarly shows that structural configuration influences stiffness and overall capacity (Embaby & El Naggar, 2025).

The maximum diagonal compressive force of 22.91 kN indicates that compressive capacity and member stability require particular attention. In bamboo, variations in diameter, wall thickness, straightness, node position, moisture content, and local defects can produce substantial variation in stiffness and strength. ISO 22156:2021 emphasizes experimentally determined characteristic values, and the preliminary assumptions used here—particularly an elastic modulus of 10 GPa and a D90/t10 section—must be replaced with actual prototype material data (ISO, 2021). The bolted joints also require direct verification because connection behavior can govern bamboo structural

performance; complete-joint testing provides an appropriate basis for this stage (Harries et al., 2022).

The relationship between a bridge intervention and agricultural downstream processing should be evaluated through observable logistics mechanisms rather than assumed benefits. A crossing structure may contribute to improved accessibility if it reduces physical access barriers and supports more reliable movement of inputs and harvested products. However, the present analysis does not demonstrate changes in selling price, productivity, transport cost, or distribution frequency. Those effects should be evaluated after implementation using the indicators defined earlier: travel time, transportation cost, trip frequency, market access, safety perceptions, volume transported, and post-harvest losses where feasible. This distinction separates verified technical outputs from community outcomes that remain to be measured.

Contribution to Community

Because the bridge has not yet been reported as a completed and tested community intervention, the contribution at this stage is a transferable planning and verification framework rather than a verified community impact. The six-stage model below separates the preliminary work already documented from the later fabrication, implementation, governance, and impact-evaluation stages. This distinction makes the evidence status of each stage explicit and prevents planned benefits from being presented as achieved outcomes.

Table 8.
Implementation-stage status and evidence for the modular bamboo bridge initiative

#	**Stage**	**Activities**	**Status and evidence**
1	Diagnosis	Identification of the access problem, review of site/location documentation, bridge span and user context.	Completed at a preliminary level. Evidence: village map, project-location photographs, partner/problem description, and project documentation (Figures 1-2). Baseline travel-time and cost measurements are not yet reported.
2	Engineering	Interpretation of drawings, Cremona truss analysis, elastic frame verification, and load-sensitivity screening.	Completed at a preliminary analytical level. Evidence: geometric/material assumptions and numerical results in Tables 1-4 and 6, with structural-response diagrams in Figures 3-4.
3	Fabrication	Bamboo selection and characterization, preservation, plate/bolt preparation, and quality control.	Not yet reported as completed. To follow material characterization, connection verification, and final design confirmation.
4	Community implementation	Bridge erection, safe-use training, and partner/community participation.	Not yet reported as completed; no attendance, training assessment, or operational-use evidence is claimed in this article.

#	**Stage**	**Activities**	**Status and evidence**
5	Governance	Operation and maintenance SOPs, management roles, and inspection checklists.	Planned. No maintenance-performance evidence is yet available.
6	Impact evaluation	Before-and-after assessment of travel time, transport cost, safety, distribution frequency, and other agreed indicators.	Planned. No before-and-after community outcome data are reported in the present preliminary phase.

Conclusion

This article reports the preliminary planning and structural-analysis phase of a modular bamboo bridge initiative for the Timun Mas Farmers Group in Purwosari Village. The proposed 13 m bridge arrangement, including an 8 m Cremona truss span, produced a maximum lower-chord tensile force of 19.80 kN, a maximum compressive force of 22.91 kN in a diagonal member, and an estimated mid-span frame deflection of 10.64 mm under the initial 5.5 kPa screening scenario. The 9.5 kPa sensitivity scenario increased global moment, deflection, and local bending response, confirming the need for load-specific final verification. These numerical results are verified outputs of the preliminary engineering stage, but they do not establish operational or vehicle-load safety. The bridge has not yet been reported here as fabricated, erected, statically load-tested, or evaluated through participant training and before-and-after community indicators. Consequently, benefits such as reduced travel time, lower transportation costs, safer access, and improved agricultural distribution remain evaluation targets rather than measured outcomes. Before community operation, the next stages should include characterization of the actual bamboo culms, detailed connection testing, final structural modelling using the intended design loads, controlled static load testing, participatory installation, safe-use and maintenance training, and partner-based evaluation of accessibility and logistics outcomes.

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