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BAMBOO REINFORCED SLABS MODELLING AND PERFORMANCE IN BUILDING STRUCTURES

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Abstract: *Bamboo, due to its rapid renewability and favourable mechanical properties, has emerged as a potential sustainable alternative to steel reinforcement in concrete structures. This study presents a numerical investigation of bamboo-reinforced concrete (BRC) slabs using finite element analysis (FEA) in ABAQUS/Standard. Concrete was modelled using 8-node brick elements (C3D8R) with a concrete damaged plasticity (CDP) model, while bamboo reinforcement was modelled using 2-node truss elements (T3D2) with linear elastic-perfectly plastic behaviour. Two slab specimens with different reinforcement configurations (BRC8: 8mm × 8mm @ 75mm; BRC10: 10mm × 10mm @ 100mm) were analysed under static point loading with fixed boundary conditions. The numerical results were validated against experimental data from Haryanto et al. (2021). The model showed reasonable agreement with experimental results, predicting ultimate loads with ≤3% error (BRC8: 30.86 kN vs 31.70 kN; BRC10: 31.72 kN vs 31.10 kN) but overestimating deflections by 16–19% (BRC8: 9.97 mm vs 8.40 mm; BRC10: 9.65 mm vs 8.31 mm). The observed discrepancies are attributed primarily to the perfect bond assumption between bamboo and concrete, simplified material properties and natural variability in bamboo samples. Linear load-deflection relationships with high correlation coefficients (R^2 = 0.98–0.99) were established for both slabs. The validated modelling framework provides a useful tool for preliminary assessment of BRC slabs; however, future work should incorporate bond-slip modelling, durability considerations, and validation with Nigerian bamboo species.*

Key words: Bamboo reinforced concrete (BRC), Finite element analysis (FEA), ABAQUS, Load Deflection Characteristics; Sustainable construction materials.

1 Introduction

There are challenges facing the construction industry due to the rise in the cost of construction materials, especially steel, which has prompted the search for alternative materials that is/are sustainable. Considering Bamboo possessed mechanical properties and rapid renewability, it has emerged as a material that can substitute reinforcement bars in concrete structures (Adewuyi *et al*, 2015).
In the southern part of Nigeria where there is high rainfall, bamboo is readily available in forest regions such as Rivers and Cross River states. This has clearly shown local and sustainable resources for construction (Atanda, 2015).
Many studies have explained the use of Bamboo as a Material for building construction purposes such as foundation, floors, walls, and roofs. This is due to its rapid growth, environmental friendliness, lightness in weight, etc.
The construction costs made acquiring a house for many impossible. The rise in construction costs and poor workmanship is contributing to the issue (Alabi and Fapohunda, 2021). Bamboo would provide a solution since it is cost-effective, durable and eco-friendly, which makes it an alternative to traditional material(s). By using bamboo as an option, it would attract more people to acquire low-cost housing (Edeoghon, 2019).
Numerical modelling is used in determining the structural performance of bamboo materials used in building construction. Studies have made use of the numerical model to fully understand the behaviour of concrete structures reinforced with bamboo under

different loading conditions (Usidamen et al, 2024). ABAQUS software has been used by many in numerical modelling of BRC structures to simulate the behaviour under different loading conditions (Thangaraj and Murugan, 2023).
Studies have indicated that bamboo can replace steel reinforcement in concrete slabs, as it showed good structural performance under various loading conditions. Despite its structural performance in concrete structures, there are challenges associated with its use, such as high absorption of water and weak bonding strength with concrete (Archila et al, 2018).
More research needs to be conducted to address challenges linked to use of bamboo as reinforcement bars in concrete structures and develop standards and/or codes for utilization of bamboo as a building material.

1.1 Challenges in Bamboo Reinforcement

Despite these advantages, several challenges restrict the widespread adoption of bamboo as reinforcement in concrete:
Durability Concerns: Bamboo is highly hygroscopic, with moisture absorption leading to swelling and shrinkage that can compromise the bamboo-concrete interface and cause micro-cracking in the surrounding concrete (Archila et al., 2018). Furthermore, bamboo is susceptible to biological degradation from fungi and termites, particularly in tropical climates (Sanchez et al., 2019). These durability issues significantly affect long-term structural performance.
Bond Behaviour: The smooth surface of bamboo culms results in poor adhesion with concrete, leading to early debonding and slip under load (Awalluddin et al., 2022). Unlike steel reinforcement, which relies primarily on mechanical interlocking through ribs, bamboo relies on chemical adhesion and frictional resistance. Bond strength is affected by bamboo surface roughness, moisture content, age, treatment method, and concrete composition (Pahuja and Ghosh, 2024).
Treatment Methods: Various treatment methods have been explored to address these challenges, including coating with epoxy, bitumen, or polymer sealants, impregnation with preservatives, and surface roughening (Thangaraj and Murugan, 2023). However, the effectiveness of these treatments varies, and optimal treatment protocols for different climatic conditions remain an area of active research (Adier et al., 2023).
Material Variability: Bamboo's mechanical properties vary significantly with species, age, moisture content, and fibre orientation, making standardization challenging (Ramesh et al., 2021). This variability introduces uncertainty in structural design and performance prediction.

1.2 Numerical Modelling of BRC Structures

Numerical modelling is increasingly used to determine the structural performance of bamboo materials in building construction. Studies have employed numerical models to understand the behaviour of concrete structures reinforced with bamboo under different loading conditions (Usidamen et al., 2024). ABAQUS software has been widely used for numerical modelling of BRC structures to simulate behaviour under various loading conditions (Usidamen et al., 2024).

1.3 Research Gap

Although numerous studies have investigated bamboo-reinforced concrete using experimental methods, limited research exists on validated numerical modelling approaches that can predict the structural behaviour of BRC elements. Specifically:

1. Existing numerical models often lack comprehensive validation against experimental data
2. Few studies have investigated different reinforcement configurations for BRC slabs
3. Quantitative relationships (e.g., load-deflection models) for design applications are limited
4. Studies on BRC slabs specifically are relatively scarce
5. The effect of model assumptions (e.g., perfect bond, boundary conditions) on prediction accuracy has not been systematically examined

Studies have indicated that bamboo can replace steel reinforcement in concrete slabs, showing good structural performance under various loading conditions (Haryanto et al., 2021). However, more research is needed to address challenges associated with bamboo reinforcement and develop standards and codes for its utilization as a building material.
Furthermore, while experimental studies have provided valuable data on BRC slabs, there is a need for validation of numerical models against independently conducted experimental work, particularly with bamboo species native to specific regions such as Nigeria. This study relies on previously published experimental data for validation, which, while providing a useful benchmark, limits the generalizability of findings to the specific bamboo species and conditions tested.

1.4 Objectives and Novelty

The objectives of this study are to:

1. Develop a validated ABAQUS modelling framework for BRC slabs
2. Compare two different bamboo reinforcement configurations (BRC8 and BRC10)

3. Establish quantitative load-deflection relationships for design applications
4. Identify and quantify sources of discrepancy between numerical and experimental results
5. Provide guidance for model refinement and future research

The novelty of this work lies in: (i) the development of a reproducible numerical framework specifically for BRC slabs, (ii) quantitative comparison of two reinforcement configurations, (iii) establishment of linear models (with R^2 values) as preliminary design tools, and (iv) identification of specific error sources to guide future research.

1.5 Materials and Method

In this study, the materials and their properties used are obtained from (Haryanto et al, 2021) in the modelling of the bamboo-reinforced concrete (BRC) slabs and are presented in Table 1.

Table 1: *Material Properties for Bamboo Reinforced Concrete Slabs*

Properties	Materials	Values	Source/Note
Density (Kg/m^3)	Concrete	2,400	Standard value
	Steel	7,870	Standard value
	Bamboo	770	Haryanto *et al*, 2021
Young's Modulus (Mpa)	Concrete	22,977	Haryanto *et al*, 2021
	Steel	200,000	Standard value
	Bamboo	17,500	Haryanto *et al*, 2021
Poisson ratio	Concrete	0.2	Standard value
	Steel	0.28	Standard value
	Bamboo	0.26	Standard value
Yield stress (Mpa)	Steel	210 – 300	Standard range
	Bamboo	50 – 85	Standard range
Compressive Strength (MPa)	Concrete	18 (M18)	Haryanto *et al*, 2021
Tensile strength (MPa)	Concrete	2.97	Calculated from compressive strength (IS 456:2000)
Plastic/Inelastic strain	Concrete	0.0035	Standard value
	Steel	0 – 0.002	Standard value
	Bamboo	0 – 0.002	Standard value
Dilation Angle	Concrete	35	CDP model parameter
Eccentricity	Concrete	0.1	CDP model parameter
Fbo/fco	Concrete	1.16	CDP model parameter
K	Concrete	0.6667	CDP model parameter
Viscosity	Concrete	0	CDP model parameter

The bamboo properties (density = 770 kg/m^3, Young's modulus = 17,500 MPa) were selected from Haryanto et al. (2021) to maintain consistency with the experimental data used for validation. It is important to note that Nigerian bamboo species (Bambusa vulgaris and Dendrocalamus giganteus) may exhibit different mechanical properties; therefore, these values should be verified with local testing for design applications in Nigeria.

The method of finite element analysis (FEA) in ABAQUS was used to model the bamboo reinforced concrete slab to determine its structural behaviour. As stated in the literature (Pahuja and Ghosh, 2024), the FEA is versatile in application. The materials (bamboo and steel) are modelled using linear elastic and plastic material models. The tensile strength was not explicitly defined in the ABAQUS material module, as the plasticity model uses yield stress and hardening data.

The bamboo reinforced concrete (BRC) slabs were reproduced using Finite Element Analysis (FEA) in ABAQUS to determine its structural behaviour. The geometry of the slab and the bamboo reinforcement was first defined. As detailed in Table 1, the properties of concrete (using a concrete damaged plasticity model) and bamboo (modelled as a linear elastic material until yield) were assigned. An interaction between bamboo and concrete was established using an embedded region constraint. A perfect bonding to simulate an ideal condition was assumed. To ensure mesh objectivity, the mesh was seeded with standard element types and a convergence study was conducted. Then an analysis step was defined (Static, General) and the edges of the slab were defined as fixed support as the boundary conditions. Having successfully defined all parameters, a concentrated load was applied at the center of the slabs, the software conducted the analysis and obtained the results for ultimate load, deflections and load displacement behaviour. The results obtained from the numerical analysis were compared with the experimental data obtained from the previous study (Haryanto et al, 2021) to validate the model created.

1.6 Specimen Configuration and Geometry

In this study, there are two slab specimens on which the finite element analysis was conducted. All the specimens have different reinforcement configurations. The geometry and reinforcement details are described below.

2.1.1 Slab Specimens

The two slabs had size of 400mm x 400mm; 75mm thick and were modelled with fixed at four edges as it is in the experimental study. The specific reinforcement configurations were as follows:

BRC8: The slab was modelled with 8mm x 8mm bamboo reinforcement spaced at 75mm centre to centre as shown in Figure 1 below.

BRC10: This slab was reinforced with 10mm x 10mm bamboo strips spaced at 100mm centre to centre. The details of the slab arrangement are presented in Figure 2.

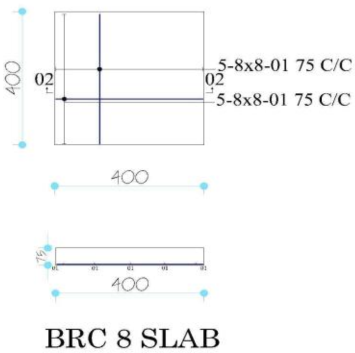


Figure 1: *The details of slab specimen (BRC 8)*

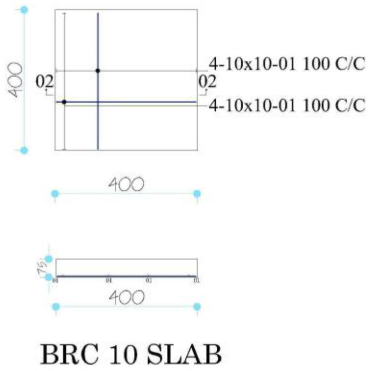


Figure 2: *The details of slab specimen (BRC 10)*

A point load was applied at the centre of the slabs to test the structural performance of the BRC slabs. The load deflection behaviour, ultimate failure loads and maximum deflections were obtained after the analysis. The details of the slab and their reinforcement are illustrated in Figures 1 and 2, which provide a clear understanding of the arrangement of the bamboo reinforcements.

1.7 The Procedure of Finite Element Analysis

The models were created in ABAQUS using the standard static/general procedure. The finite element analysis was conducted using ABAQUS/Standard and followed these steps:

i. Material properties were defined (see Table 1) and assigned to the respective parts (concrete, bamboo, steel).
ii. A perfect bond was assumed between bamboo reinforcement and concrete using the embedded region constraint in ABAQUS. This simplification neglects potential bond slip behaviour, which is later discussed as a source of discrepancy.
iii. The slab parts were created and assembled by creating instances and reorient them within the assembly model. The reinforcement (main bars and stirrups) was positioned at the centre of the concrete as per the experimental setup as shown in Figure 3.

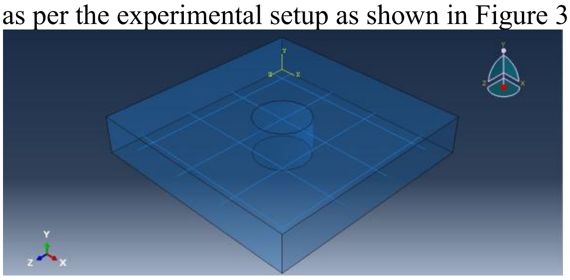


Figure 3: *Slab Parts Assembly.*

iv. The models were meshed using standard element type for structural applications. For concrete, 3D solid type was used and for the reinforcement (bamboo and steel), they were modelled as truss elements and embedded within the concrete solid mesh. The mesh global size of 40 was used for the slab parts. The concrete meshing is shown in Figure 4 below.

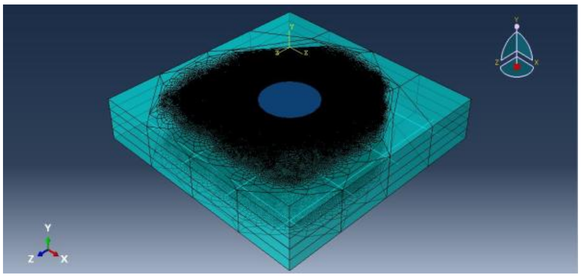


Figure 4: *Concrete Slab Meshing.*

v. Boundary conditions and loads were applied to simulate the experimental setup. As shown in figure 5, the four sides of the slabs were fixed to simulate continuous slab applications.

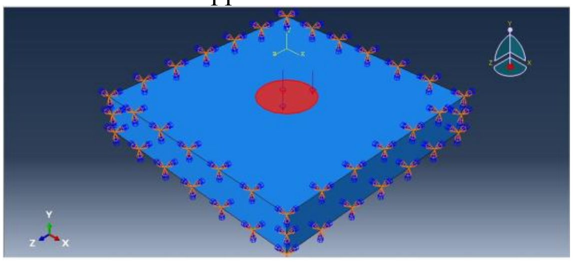


Figure 5: *Load and Boundary Condition of the Slab.*

However, the solver settings and convergence criteria selected for the model are presented in Table 2.

Table 2*: Solver Settings and Convergence Criteria*

Parameter	Setting
Analysis Type	Static, General
Solver	Direct/Solver default/Full Newton
Maximum Number of Increments	100000
Initial Increment Size	0.1
Minimum Increment Size	1e-5
Maximum Increment Size	1
Convergence Criterion (Displacement)	0.001 (relative)
Convergence Criterion (Residual Force)	0.005 (relative to applied load)
Load Application	Monotonic, point load at centre

vi. The models were analysed and results for load, deflection, and failure modes were extracted.

To confirm the validity of the models, the numerical results obtained were compared with the results of experimental data adopted from the literature Haryanto *et al*, 2021.

1.8 Mesh Convergence Analysis

To ensure mesh objectivity, a convergence study was conducted with mesh sizes ranging from 20mm to 50mm. The results are presented in Table 3.

Table 3: *Mesh Convergence Study Results*

Mesh size (mm)	Elements (Approx.)	Nodes	Ultimate Load (kN)	% Difference from 40 mm
20	64,000	68,921	31.21	+1.13
30	18,963	21,000	30.95	+0.29
40	8,000	9,261	30.86	Reference
50	4,096	4,913	30.21	-2.11

The 40mm mesh size was selected as it provides a balance between computational efficiency and accuracy, with <2% variation from the finer 20mm mesh. The corresponding element and node count for the selected mesh are obtained from ABAQUS mesh module and presented in Table 3.

1.9 Model Limitations

Several important limitations of the numerical model should be acknowledged:

The numerical models were validated using experimental data from Haryanto et al. (2021), which was conducted with Indonesian bamboo species (*Dendrocalamus asper*). No independent experimental work was conducted in this study to validate the models with Nigerian bamboo species. The validation is therefore limited to the specific specimens, bamboo species, and conditions reported in that study.

This study is a numerical investigation only, new experiments were not conducted, including bond testing, slab testing, or durability assessments. This limits the ability to assess the model's performance for different bamboo species, treatment methods, or environmental conditions.

2 Results and Discussion

The load displacement curves of the numerical analysis show that both BRC8 and BRC10 slabs expressed linear elastic behaviour.

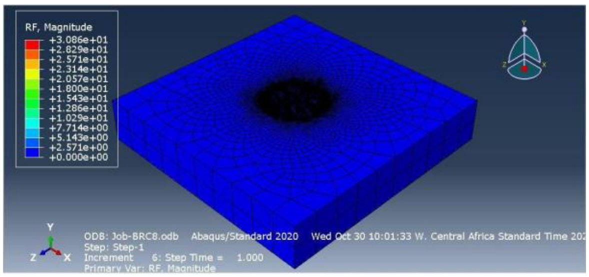
Table 4: *Results of Experimental and Numerical Analysis of Bamboo Reinforced Concrete Slab*

Slab	Ultimate Failure Load (kN)		Maximum Deflection (mm)	
	Experimental	Numerical	Experimental	Numerical
BRC8	31.70	30.86	8.40	9.97
BRC10	31.10	31.72	8.31	9.65

Table 5: *Error Analysis of Numerical Model Predictions*

Metric	BRC8	BRC10
Absolute Error – Load (kN)	0.84	0.62
Percentage Error – Load (%)	2.65	1.99
Absolute Error – Deflection (mm)	1.57	1.34
Percentage Error – Deflection (mm)	18.7	16.1
MAE – Load (kN)	0.73	
RMSE – Load (kN)	0.73	
MAE – Deflection (mm)	1.46	
RMSE – Deflection (mm)	1.46	

In Table 4, the ultimate failure loads of BRC8 and BRC10 are 30.85 kN and 31.72 kN as shown in Figures 3a and 3c, while the corresponding maximum deflections are 9.97 mm and 9.65 mm as clearly shown in Figures 6b and 6d. The experimental results (ultimate failure loads and maximum deflections) from the referenced literature (Haryanto *et al*, 2021) are 31.70 kN and 31.10 kN; 8.40 and 8.31 mm respectively which is almost same with that of numerical analysis.
As shown in Table 5, the numerical model predicts ultimate failure loads with high accuracy, with percentage errors of only 2.65% for BRC8 and 1.99% for BRC10. The overall MAE and RMSE for load predictions are both 0.73 kN, indicating consistent accuracy across both specimens. However, the model overestimates deflections by approximately 16–19% (BRC8: 18.69%; BRC10: 16.13%). This indicates that while the model captures strength reasonably well, it is less accurate in predicting stiffness. The MAE and RMSE for deflection predictions are both 1.46 mm, reflecting the consistent bias towards over estimation.
The differences between numerical and experimental results are as a result of assumptions made by the numerical model and variability in bamboo samples during experimental testing (Usidamen *et al*, 2024). The two results aligned with the deflection limit of span/250 (≈11.2 mm for a 2.8 m span) prescribed by Euro code 2 (2004) for serviceability and meet the minimal safety factor of 1.5 for ultimate load capacity needed by ACI 318-19, 2019, IS 456:2000, 2000. However, the study accepts the limitations highlighted in literature which include reduction in load capacity due to inadequate bamboo concrete bonding in real conditions compared to numerical models (Awalluddin et al., 2022), and long-term durability concerns of bamboo in aggressive environments (Sanchez *et al*, 2019).



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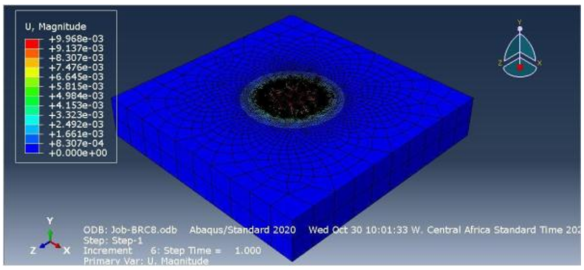

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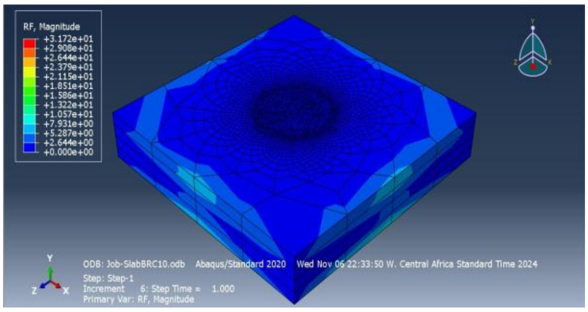

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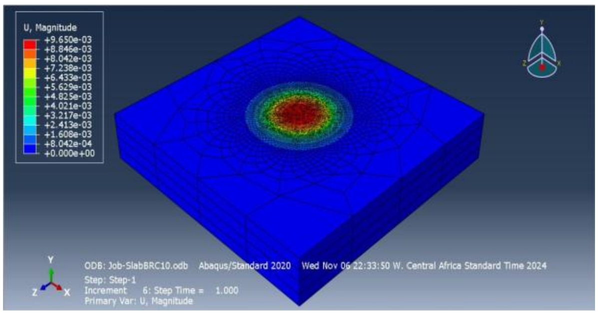
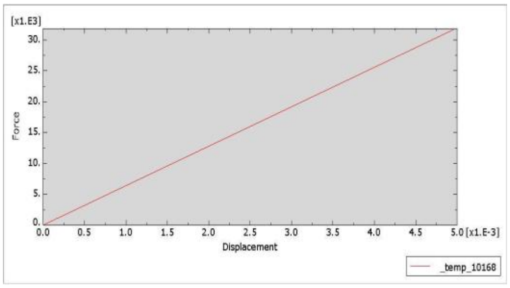


d

Figure 6 (a - d): *Numerical Contour Results*

Figure 6: Numerical simulation results from ABAQUS for bamboo-reinforced concrete slabs: (a) Stress distribution contour under load for slab BRC8; (b) Deformation contour showing deflection (mm) for slab BRC8; (c) Stress distribution contour for slab BRC10; (d) Deformation contour for slab BRC10.



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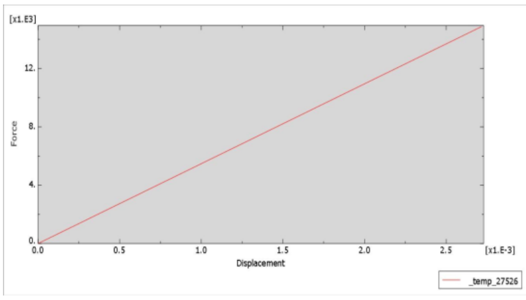

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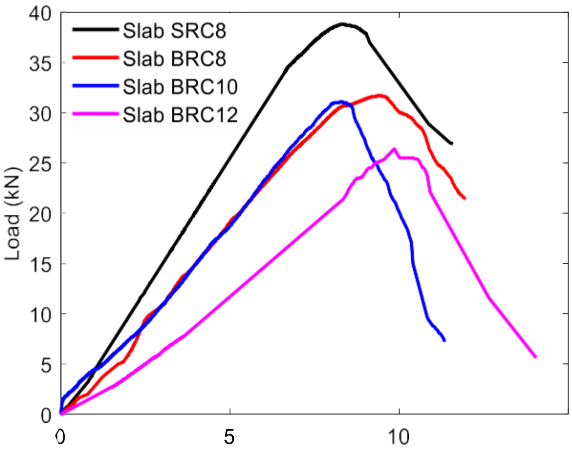

c

Figure 7 (a – c): *Numerical and Experimental Load-Deflection Behaviour*

Figure 7: Numerical simulation results from ABAQUS for bamboo-reinforced concrete slabs: (a) Numerical load-deflection curve for slab BRC8; (b) Numerical load-deflection curve for slab BRC10; (c) Experimental load-deflection curve for BRC8 and BRC10.

A comprehensive investigation of bamboo reinforced concrete (BRC) slabs was conducted in this research. An experimental data was used as inputs in numerical analysis using ABAQUS software (Usidamen *et al*, 2024). The numerical results of both specimens (BRC8 & BRC10) show some variations in failure loads and deflections compared with the experimental results. Differences between experimental and numerical results were observed. In experimental analysis, the load capacity decreased with increased bamboo reinforcement, numerical modelling showed an increased capacity. The difference might be as a result of the following factors:

1. Material Variability: The diversity in natural Bamboo's diversity, such as defects, moisture content and fiber alignment can significantly affect its mechanical properties (Ramesh *et al*, 2021). The results of experimental analysis will frequently reflect the variability while the numerical model assumes idealized conditions.
2. Bonding Behaviour: For effective load transfer, the bond between bamboo and concrete is critical. In addition, the imperfect bonding in experimental settings usually leads to early failure through debonding and slip, this is one of the major findings in the assessment of bamboo concrete (Terai, 2024). While for numerical models, it relies solely on the simplifying assumption of perfect bonding.
3. Boundary conditions: In numerical simulations, the idealized boundary conditions may not fully capture real world constraints. Accurate modelling of supports is crucial for correlating numerical and physical test results (Siqueira et al., 2025).

Remarkably, the experimental and numerical results for the BRC8 and BRC10 slabs confirmed the presence of linear elastic deformation characteristics.

In the experimental data (Haryanto *et al*, 2021), it is observed that the BRC slabs are of linear elastic behaviour which emphasized the structural suitability of bamboo for low-cost housing in developing countries. It was supported by research by (Bredenoord, 2024) on review of bamboo's material properties.

But research by (Sanchez *et al*, 2019), argues that the long-term durability of bamboo in concrete is a concern as a result of being prone to moisture absorption and fungal attack, which could lead to low experimental failure loads.

However, a comprehensive assessment must consider more dynamic real-world conditions.

In research conducted by (Elsayed *et al*, 2025), a non-linear behaviour in BRC slabs was observed under cyclic loading. It suggested that linear elastic models might not fully represent performance in seismic events scenarios. It also indicated that it will be suitable for many contexts, but for the high-risk zones, there is need to refine the design methodologies for bamboo reinforced concrete.

In Figure 7c, the load-deflection behaviour of the two bamboo-reinforced concrete (BRC) slab specimens (BRC8 and BRC10) under experimental testing was graphically represented. It shows how each slab deflects as the applied load increases until it fails. For the numerical load deflection curves (Figure 7a and 7b), the simulation predicts linear elastic behaviour of the structural elements (slabs) under the specified loading conditions.

3.1 Load-Deflection Data Analysis and Mathematical Modelling

A relationship was established for the load deflection behaviour of BRC slabs which is of linear form y = mx, where y is the load (kN); x is the deflection (mm) and m is the slope (structural stiffness). The linear models of both experimental and numerical analysis established are summarized in Table 6. The high correlation coefficients (R^2 = 0.98-0.99) confirm a strong linear fit, consistent with the findings of (Haryanto *et al*, 2021).

***Table 6:** Structural Elements Linear Models*

S/No	Elements	Trends	Mathematical Relationship		Correlation (R^2)	Reference
			Experimental	Numerical		
1	Slab BRC8	Linear Model	y = 31.7x	y = 30.86x	0.98	(Haryanto *et al*, 2021)
2	Slab BRC10	Linear Model	y = 31.1x	y = 31.72x	0.99	

The slope m represents the ratio of the vertical change y to the horizontal change x. For example, in the case of Slab BRC8, the experimental relationship is y=31.7x, meaning that for every unit increase in x, y increases by 31.7 units.
The slope physically represents the initial secant stiffness (ratio of load to deflection) of the slab, which is a measure of the slab's resistance to deformation under applied load. A higher slope indicates a stiffer slab that deflects less for a given load.
The stiffness values are presented in Table 7.

***Table 7:** Stiffness Values*

Slab	Slope (Experimental) (kN/mm)	Slope (Experimental) (kN/mm)	Difference (%)
BRC8	31.7	30.86	-2.65
BRC10	31.1	31.72	+1.99

For Slab BRC8, the experimental and numerical stiffness's are 31.70 kN/mm and 30.86 kN/mm.
Interpretation: For every 1 mm of deflection at the centre of the slab, the applied load increases by approximately 31.7 kN (experimental) or 30.86 kN (numerical). The numerical model slightly underestimates stiffness by 2.65%, meaning it predicts slightly more deflection (softer behaviour) than the experimental test.
While for Slab BRC10, the experimental and numerical stiffness are 31.10 kN/mm and 31.72 kN/mm.
Interpretation: For every 1 mm of deflection, the applied load increases by approximately 31.1 kN (experimental) or 31.72 kN (numerical). The numerical model slightly overestimates stiffness by 1.99%, meaning it predicts slightly less deflection (stiffer behaviour) than the experimental test.
From the experimental results, BRC8 is 1.93% stiffer than BRC10. This suggests that the 8mm × 8mm reinforcement spaced at 75mm c/c provides slightly higher stiffness than the 10mm × 10mm reinforcement spaced at 100mm c/c.
While from the numerical results, BRC10 is 2.79% stiffer than BRC8. This suggests that the larger reinforcement (10mm × 10mm) provides slightly higher stiffness.
The linear model y = mx is valid only within the elastic range of loading. It does not capture nonlinear behaviour beyond the yield point or failure. The model serves primarily as a simplified tool for initial design estimation and should not be extrapolated beyond tested loads. The relationship may also vary with boundary conditions, material properties, and reinforcement configurations not investigated in this study.

3 Contribution to Knowledge and Comparison with Previous Studies

The findings of this study make several contributions to the understanding of BRC slabs:
The error analysis presented in Table 5 (MAE = 0.73 kN for load; MAE = 1.46 mm for deflection) provides quantitative benchmarks for future numerical studies. Previous studies (Thangaraj and Murugan, 2023; Usidamen et al., 2024) reported model validation but did not provide comprehensive error metrics. The present study establishes that numerical models can predict ultimate load with <3% error, but deflection prediction requires refinement.
This study demonstrates that increasing bamboo reinforcement from 8mm×8mm @ 75mm to 10mm×10mm @ 100mm has a minor effect on initial stiffness (+2.8% numerically, -1.9% experimentally). This finding suggests that for the range of reinforcement configurations tested, the structural behaviour is similar, potentially allowing for design

flexibility based on available bamboo sizes. This extends the findings of Haryanto et al. (2021), who observed similar behaviour but did not quantify the comparative performance numerically.
The linear relationships y = 31.7x (experimental, BRC8) and y = 31.72x (numerical, BRC10) provide simple tools for preliminary design estimation. These models are consistent with Euro code 2 (2004) serviceability limits (span/250 ≈ 11.2 mm) and ACI 318-19 (2019) safety factors (1.5 for ultimate load), demonstrating that BRC slabs can meet code requirements for low-cost housing applications.
The study quantitatively identifies bond-slip as the primary cause of deflection overestimation (16–19%). (Awalluddin et al., 2022) reported that bond-slip can reduce load capacity, which is consistent with our findings. This provides clear direction for future work: bond-slip modelling is essential for accurate deflection prediction.
The results align with the experimental findings by Haryanto et al. (2021), who reported linear elastic behaviour for BRC slabs. The load capacities obtained from the experimental study are consistent with the range of values reported in the literature for bamboo-reinforced concrete elements of comparable dimensions (Adegbesan et al., 2026).

5 Conclusion

This study presents a numerical investigation of bamboo-reinforced concrete (BRC) slabs using ABAQUS finite element analysis, with validation against experimental data from Haryanto et al. (2021). The following conclusions are drawn:

1. The developed ABAQUS model shows reasonable agreement with experimental results, predicting ultimate loads with ≤3% error (BRC8: 30.86 kN vs 31.70 kN; BRC10: 31.72 kN vs 31.10 kN). However, the model overestimates deflections by 16–19% (BRC8: 9.97 mm vs 8.40 mm; BRC10: 9.65 mm vs 8.31 mm), primarily due to the perfect bond assumption and idealized boundary conditions.
2. Both the numerical and experimental results demonstrate that BRC slabs exhibit linear elastic behaviour under static loading conditions, with high correlation coefficients (R^2 = 0.98–0.99) for the load-deflection relationship. The linear models (y = mx) provide a simplified tool for preliminary design estimation.
3. The reinforcement configuration showed minor influence on initial stiffness, with BRC10 (10mm × 10mm @ 100mm) exhibiting slightly higher stiffness (+2.8%) than BRC8 (8mm × 8mm @ 75mm) in the numerical analysis.
4. The observed discrepancies between numerical and experimental results are attributed to: (a) material variability in natural bamboo samples, (b) imperfect bond between bamboo and concrete in experiments vs perfect bond assumption in the model, (c) differences in boundary conditions (fixed vs simply supported), and (d) simplified material models that do not capture full nonlinear behaviour.
5. The validated modelling framework provides a useful tool for preliminary assessment of BRC slabs. The linear load-deflection relationships and quantitative error analysis can inform future model refinements and provide baseline data for design applications.

This study is a numerical investigation that utilized previously published experimental data for validation. The authors did not conduct new experimental work, including bond testing, slab testing, or durability assessments. The validation is therefore limited to the specific specimens, bamboo species, and conditions reported in Haryanto et al. (2021). This limitation underscores the need for future independent experimental validation, particularly with Nigerian bamboo species and under local climatic conditions.

Limitations and Future Work:

The following limitations must be acknowledged:

1. The study only investigated small-scale slabs (400mm × 400mm)
2. Only static short-term loading was considered
3. The model assumes perfect bond between bamboo and concrete
4. Durability, creep, shrinkage, fire resistance, and long-term degradation were not evaluated
5. Bamboo properties are based on a specific species and moisture condition
6. No experimental validation with Nigerian bamboo species was conducted.

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