Enhancing Structural Efficiency In 3D Printed Concrete Beams Through Truss Topology And Barbed Wire Reinforcement

Sajitha R Nair[1], Akshaya P R[2], Dr. Praveen Nagarajan[3], Dr. Santosh G Thampi[4], Rajesh P[5].

[1,5]Research Scholar, Department of Civil Engineering, NIT, Calicut, Kerala, India

[2]Department of Civil Engineering, NSSCE, Palakkad

[3,4]Professor, Department of Civil Engineering, NIT, Calicut, Kerala, India

[a] sajitha_p230172ce@nitc.ac.in, [b] akshayaramesh1999@gmail.com , [c] praveen@nitc.ac.in ,
[d] santosh@nitc.ac.in , [e] rajesh_p230155ce@nitc.ac.in

Abstract

3D printing, or additive manufacturing, revolutionizes the transformation of digital geometric representations into tangible objects through extrusion. This innovative technology has various applications, such as cost reduction in construction, time savings, reduced reliance on manual labour improved construction safety, and enhanced environmental sustainability. However, a key challenge in adopting 3D concrete printing lies in reinforcing printed components to meet structural standards under varying loads. This study proposes an inventive solution by replacing conventional 3D printed beams with truss topology beams, reinforced using high-tensile barbed wires. This approach not only reduces material consumption but also strengthens hollow truss topology beams, utilizing galvanized steel barbed wires with superior tensile strength. The ANSYS software facilitates modelling and analysis, determining the optimal number of barbed wires for enhanced strength. The paper concludes with a comparative analysis of conventional 3D printed concrete and barbed wire-reinforced truss topology beams based on ultimate load-carrying capacity.

Keywords : 3D printing, additive manufacturing, truss topology beams, high tensile barbed wires, environmental sustainability, material consumption, structural performance

INTRODUCTION

Digital fabrication processes have the potential to expand the boundaries of architectural design and construction.3D printing is a transformative technology that has the potential to reshape traditional constructional practices.it has unique capability to create complex shapes optimize material use and reduce waste compared to conventional methods.3D printing technology allows for the precise deposition of concrete material, optimizing resource utilization and minimizing waste. By using eco-friendly binders like Ground Granulated Blast Furnace Slab (GGBS) or incorporating recycles aggregates,3Dprinting can significantly lower the carbon footprint of construction. By introducing 3D printing in the context of sustainability, it will help to achieve more environmentally responsible and socially conscious construction practices.

3D printing technology emerges as a promising alternative for automating construction processes. It allows for the rapid printing of full-scale structures, reducing construction time and waste generation [12].3D concrete printing involves the use of digitalized model data to guide printing equipment in the continuous deposition of materials. This layer manufacturing processes enables the creation of intricate multi-scale structures [10]. This technology can significantly reduce labour requirements and construction costs. While 3D structures provide efficient construction methods, they may not always meet required strength standards. To address this challenge this paper introduces a novel method for reinforcing 3D printed concrete structures using barbed wires. Barbed wires made of galvanized steel possess greater tensile strength than conventional steel bars [6] Barbed wires, characterized by their exceptional tensile strength, serve as an innovative alternative to conventional steel reinforcement. Various numbers of barbed wires are strategically integrated into the tension zone of the beams to bolster their strength. In an effort to enhance the economy of 3D printed structures, truss topology designs are employed in place of solid structures [13].

A hollow topology in 3D printed beams can offer several advantages such as reduced weight, material savings resource efficiency etc. There are mainly 4 hollow topology beams they are cellular, lattice, truss and triangular. Modelling and analysis are done by ANSYS software. Barbed wires are used as reinforcing material in 3D printed concrete as an alternative to conventional steel reinforcement. Barbed wires are

galvanized steel wires that have greater tensile strength. Barbed wires are provided at different numbers in tension zone to obtain better strength. Optimum number of barbed wires to obtain better strength is determined in this paper Comparison between the conventional 3D Printed concrete and hollow topology beams that reinforced by barbed wires based on its ultimate load carrying capacity is also included in this paper

Modelling and analysis of unreinforced 3d printed concrete.
Ansys is employed to model and analyse the structural characteristics of hollow topology beams
Material Property.

In order to model the 3D printed beam using ANSYS we have to assign material properties which includes density, young's modulus (Ex, Ey&Ez) in X, Y, Z directions [2]. Orthotropic properties are assigned to the beam hence the properties in both faces are different. Shear modulus (G $_{XY}$, G $_{YZ}$, G $_{XZ}$) has to be provided in XY, YZ, XZ directions and poisons ratio(ν_{XY}, ν_{YZ}, ν_{XZ}),has to be provided in XY, YZ, XZ directions. Using Mentrey William base uniaxial (σc, σt) and biaxial compressive strength is assigned. (σbc)))

Table 1: Material Properties

Properties	Value	Unit
Density	2090	Kg/m³
E x	2.29E+09	Pa
Ey	5.76E+09	Pa
Ez	2.29E+09	Pa
ν_{XY}	0.12	
ν_{YZ}	0.12	
ν_{XZ}	0.12	
G $_{XY}$	1.04E+09	Pa
G $_{YZ}$	2.618E+09	Pa
G $_{XZ}$	1.04E+09	Pa
Menetrey William base		
σc	30.8	MPa
σt	1.62	MPa
σbc	37.5	MPa
ϕ	0.5236	Radians

Modelling
Beam of size 2000x150x300 mm is made. Mesh of size 55 mm. Boundary conditions assigned are simply supported at both ends and remote displacement is provided at top
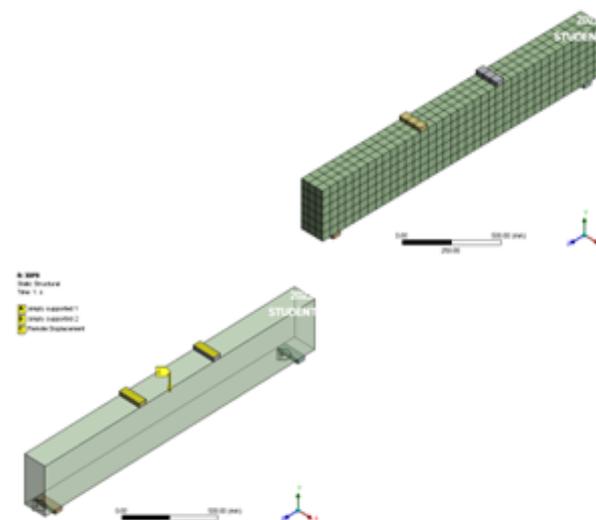

Fig 1: Mesh and boundary conditions applied on unreinforced beam.
Analysis
In analysis we get total deformation and equivalent plastic strain values. ultimate load corresponding to total deformation can be obtained.
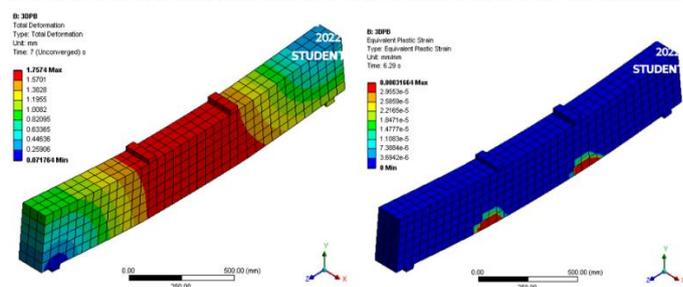

Fig 2: total deformation and equivalent plastic strain
Determining optimum number of barbed wires in 3D printed solid beam
Properties Assigned

Properties are assigned to barbed wire which includes the density, young's modulus poisons ratio, bulk modulus, shear modulus and yield strength. These properties are enlisted in Table 4 with reference to [6]

Table 4. Properties assigned to barbed wires.

Properties	Values	Unit
Density	7850	.Kg/m³
Young's modulus	2E+11	Pa
Poisson's ratio	0.3	
Bulk modulus	1.667E+11	Pa
Shear Modulus	7.692E+10	Pa
Yield strength	1150	MPa

Models of 3d printed beams with barbed wires

Barbed wires are provided at different rows and columns and need to optimum wires and numbers to be used to reinforce the 3D printed beam from 2 numbers to 24 numbers barbed wires are provided. Optimum location means whether it need to be provided in tension face or compression is to be determined

Table 5: cases

Cases	Models
Case 1	1 row 4 columns 4 no's
Case 2	2 rows 4 columns 8 no's
Case 3	3 rows 4 column 12 no's
Case 4	4 rows 4 columns 16 no's
Case 5	5 rows 4 columns 20 no's
Case 6	6 rows 4 columns 24 no's
Case 7	1 row 2 columns middle 2 no's
Case 8	2 rows 2 columns ends no's
Case 9	4 row 4 column 16 no's(1 row at top face)

Case 1
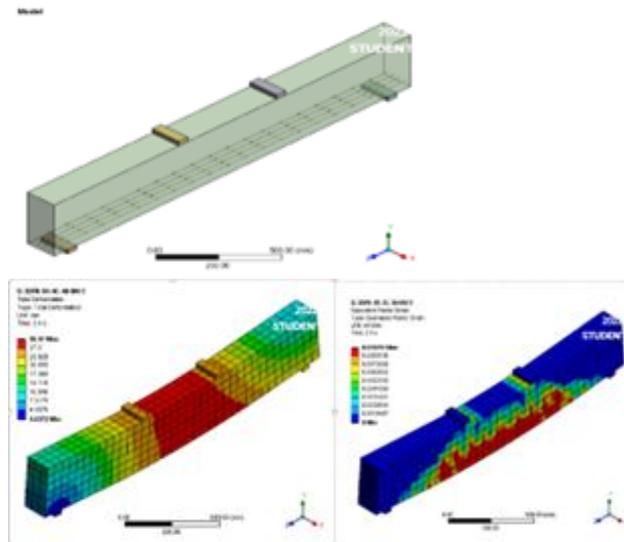
Fig 3: Model of 1 row 4 column 4 no's   **Fig 4: Total deformation and Equivalent plastic strain**

Case 2
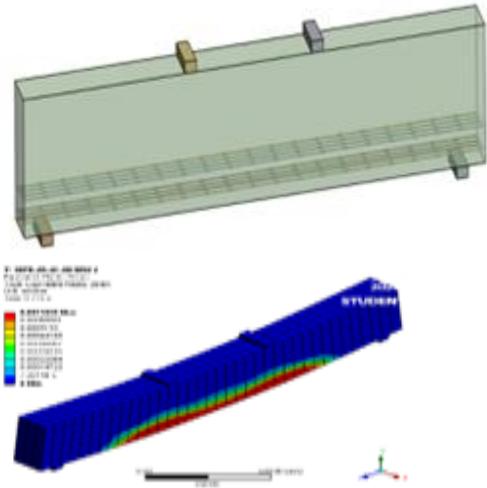
Fig 5: Model of 2 row 4 column 8 no's
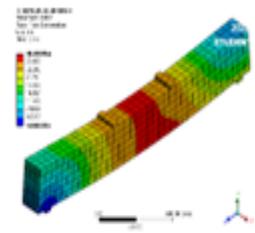
Fig 6: Total deformation and Equivalent plastic strain
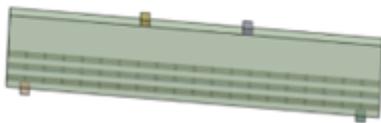
Case 3

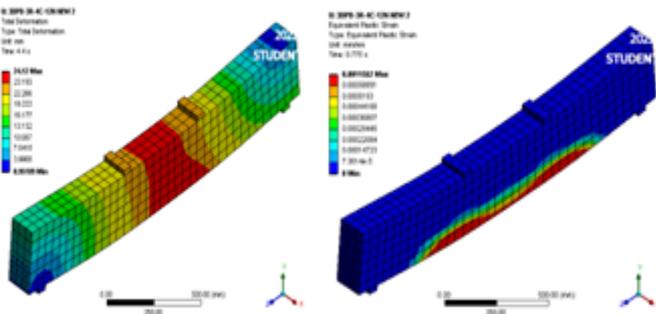Fig 7: Model of 3 row 4 column 12 no's

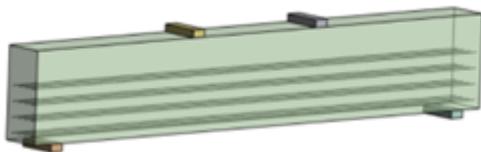Fig 8: Total deformation and Equivalent plastic strain
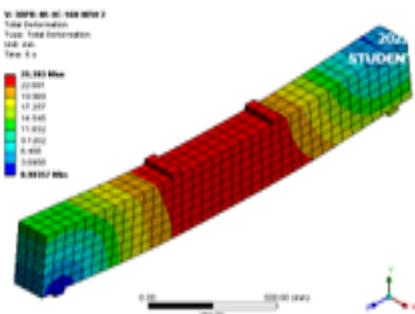
Case 4

Fig 9: Model of 4 row 4 column 16 no's

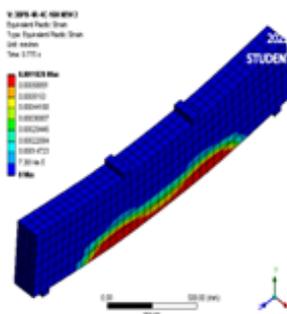
Fig 10: Total deformation and Equivalent plastic strain
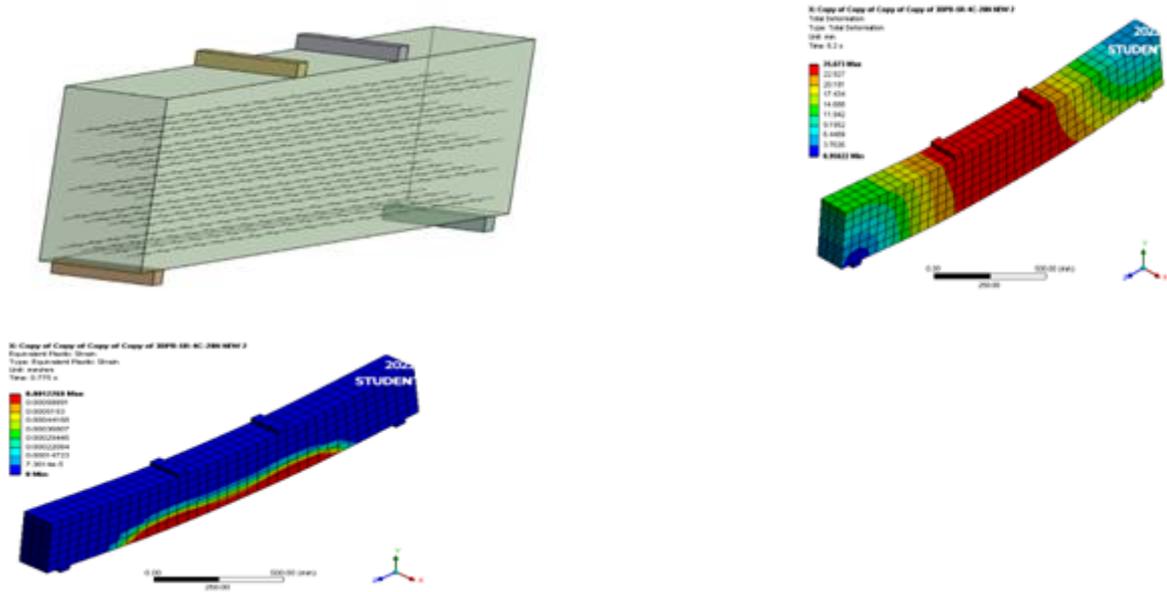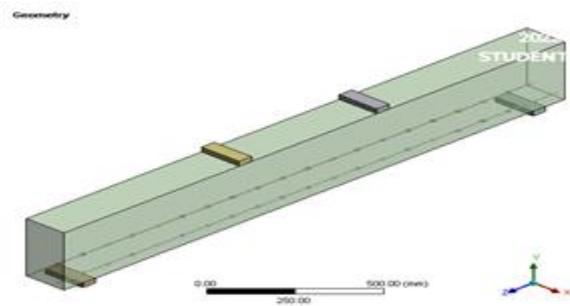
Fig 11: Model of 5 row 4 column 20 no's

Case 5

Fig 12: Total deformation and Equivalent plastic strain

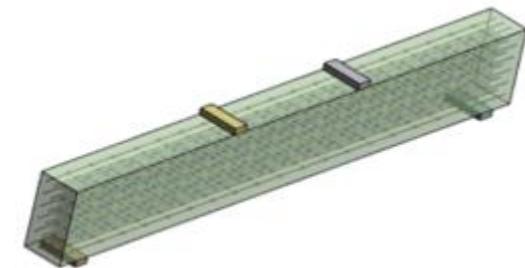**Fig 13: Model of 1 row 2 column end 2 no's**
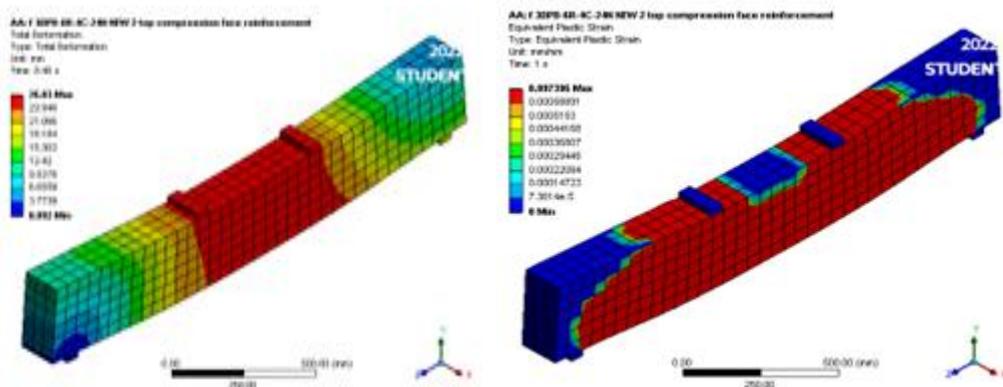**Case 6**

Fig 14: Model of 6 row 4 column 24 no's

Fig 15: Total deformation and Equivalent plastic strain
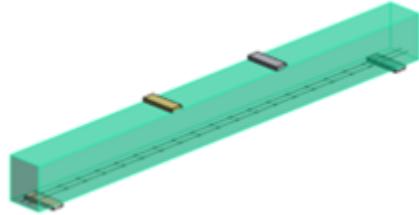**Case 7**

Fig 16: Model of 1 row 2 column middle 2 no's
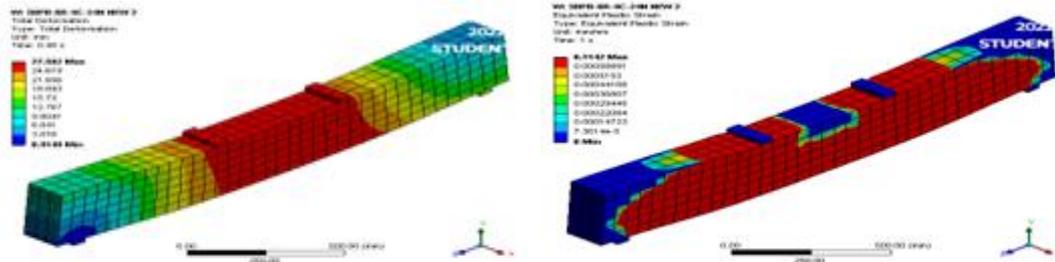

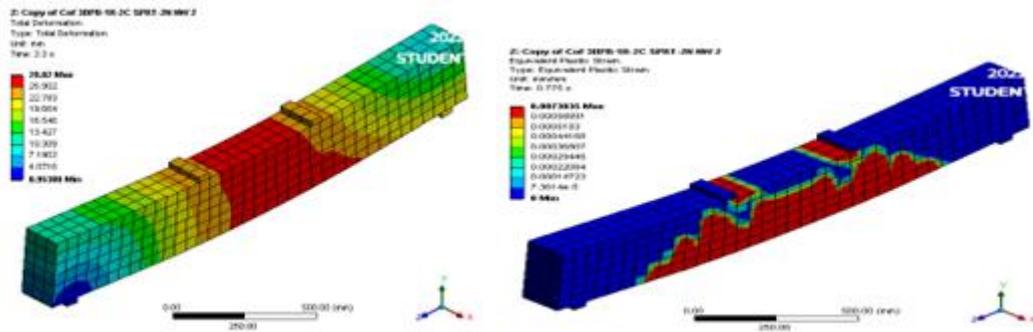**Fig 17: Total deformation and Equivalent plastic strain**

Case 8

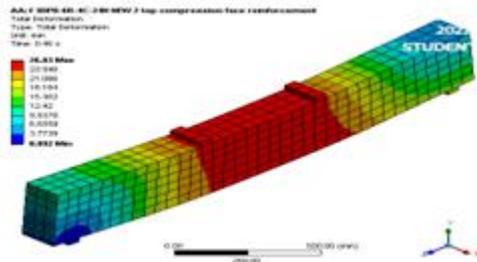**Fig 18: Total deformation and Equivalent plastic strain**

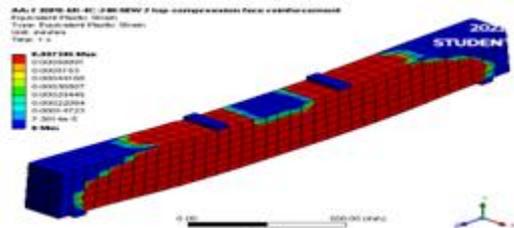**Fig 19: Model of 4 row 4 column 1 row at compression face**
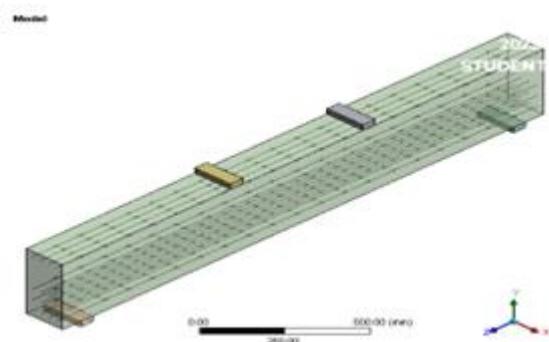

Fig 20: Total deformation and Equivalent plastic strain

Case 9

Modelling and analysis of unreinforced truss topology beams

There are mainly 4 topology they are cellular, lattice, truss, triangular. This work concentrates on truss topology. Because truss beam shows the smallest tensile strain at the peak load, crediting the best flexural deformation-resistant capacity [13].truss beams are made keeping the cross sectional area of solid beam constant and volume of concrete used for making truss topology is kept constant .Area of solid beam and truss beam is 45,000mm³.Dimension of beam is 2000x210x340mm.thickness is 30mm for truss topology.
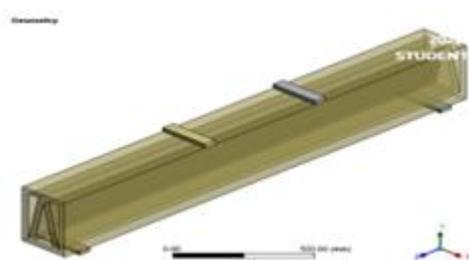

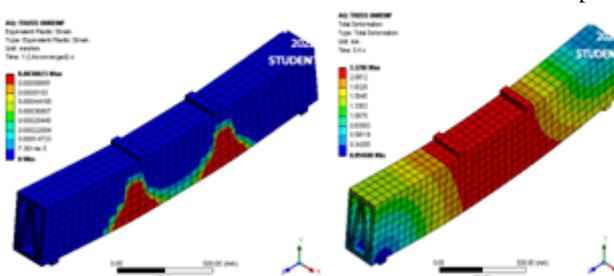**Fig 21: Model of truss topology beam unreinforced**

Fig 22: Total deformation and Equivalent plastic truss topology beam

Modelling and analysis of truss topology beams reinforced with barbed wires

Barbed wires are provided in truss topology beams. number of barbed wires is limited to 8-12 numbers for obtaining better strength. from the analysis of solid 3 d printed beam we can know the optimum number to be used is within 8-12 in the tension zone.3 models are created and analysis is done

Table 6: cases and models

Cases	Models
Case 1	Barbed wires are provided with 8 numbers
case 2	Barbed wires are provided with 10 numbers
case 3	Barbed wires are provided with 12 numbers.

Case 1

Fig 23: Reinforced truss topology beams reinforced with 8 numbers of barbed wires with 2 at ends

Fig 24: Total deformation and Equivalent plastic strain of reinforced truss topology beam Case 2

Fig 25: Total deformation and Equivalent plastic strain of reinforced truss topology beam

Fig 26: Reinforced truss topology beams reinforced with 8 no's of barbed wires with 2 at middle and cross section
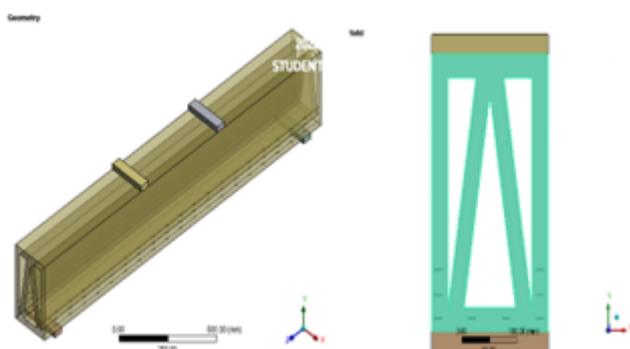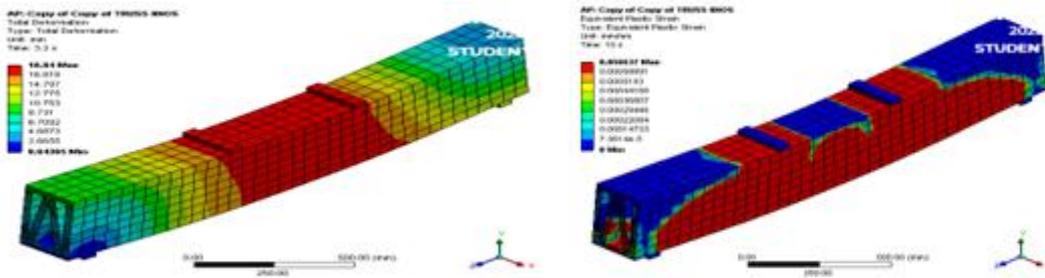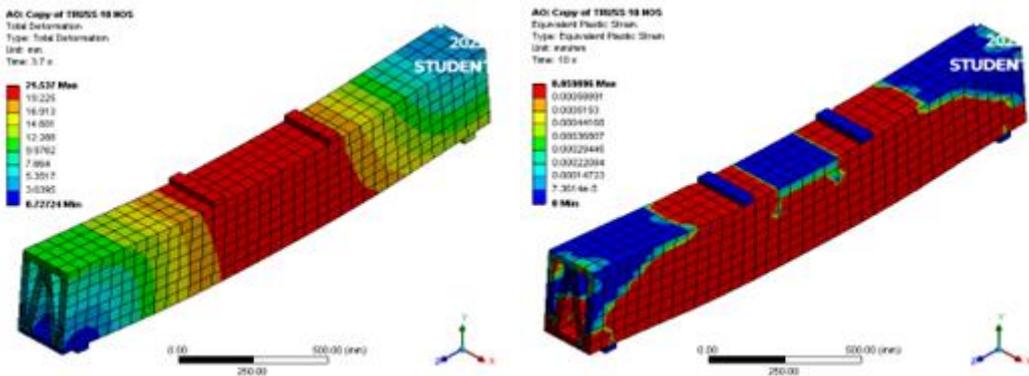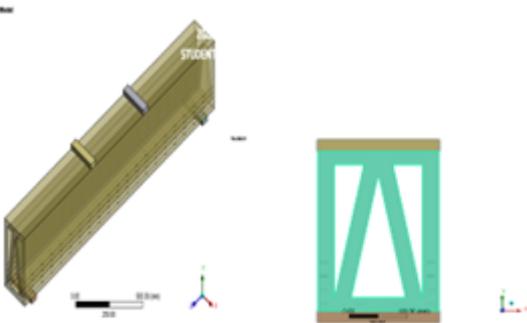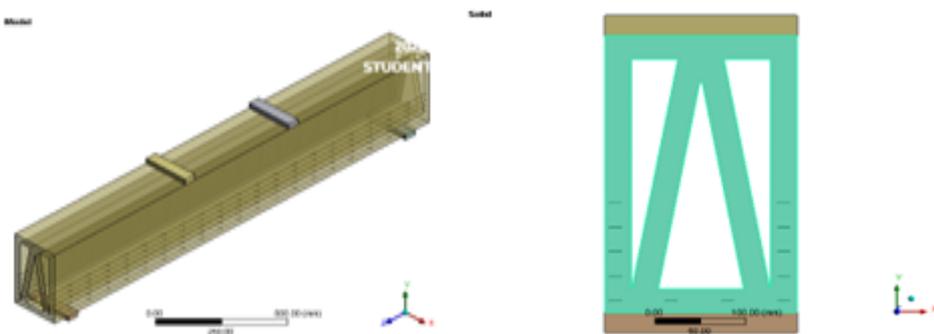Case 3

Fig 27: Reinforced truss topology beams reinforced with 12 numbers of barbed wires
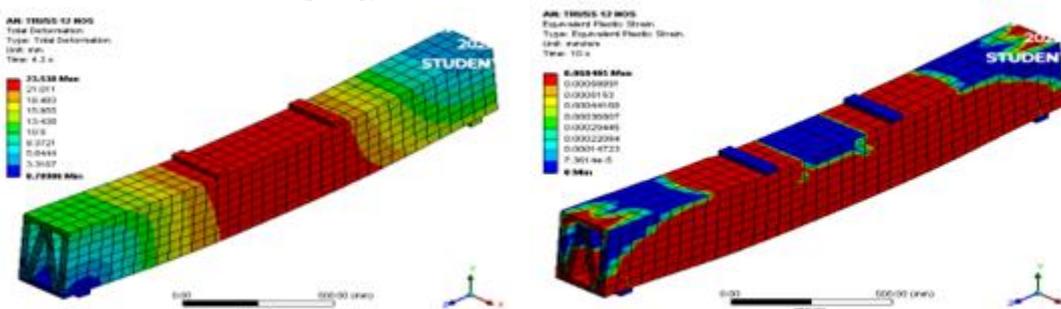
Fig 28: Total deformation and Equivalent plastic strain of reinforced

Models	Deflection	Load	Increase in load
Truss un reinforced	2.3296	26.61	1
Truss reinforced with 8 numbers of barbed wires	18.84	195.05	168.44
Truss reinforced with 10 numbers of barbed wires	21.53	225.07	198.46
Truss reinforced with 12 numbers of barbed wires	23.538	245.69	219.08

From the analysis carried out using ANSYS work bench the ultimate load and the corresponding deformation values are plotted. From the tabular values 8-12 numbers can be used in tension zone to reinforce the 3D printed beam. Corresponding load deflection curves is plotted From the results from solid beam truss topology beam is modelled using 8-12 numbers of barbed wires .4 models and the corresponding load, deflection values is plotted cases includes unreinforced truss beam, truss beam reinforced with 8 numbers ,10 numbers,12 numbers of barbed wires. when truss beam is reinforced with 12 numbers of barbed wires it can withstand load of 245.69kN. Hence 12 numbers can be used at tension zone to get better strength. Deflection of truss beam reinforced with 12 numbers is 10.10 times more than truss unreinforced beam hence it shows better ductility.
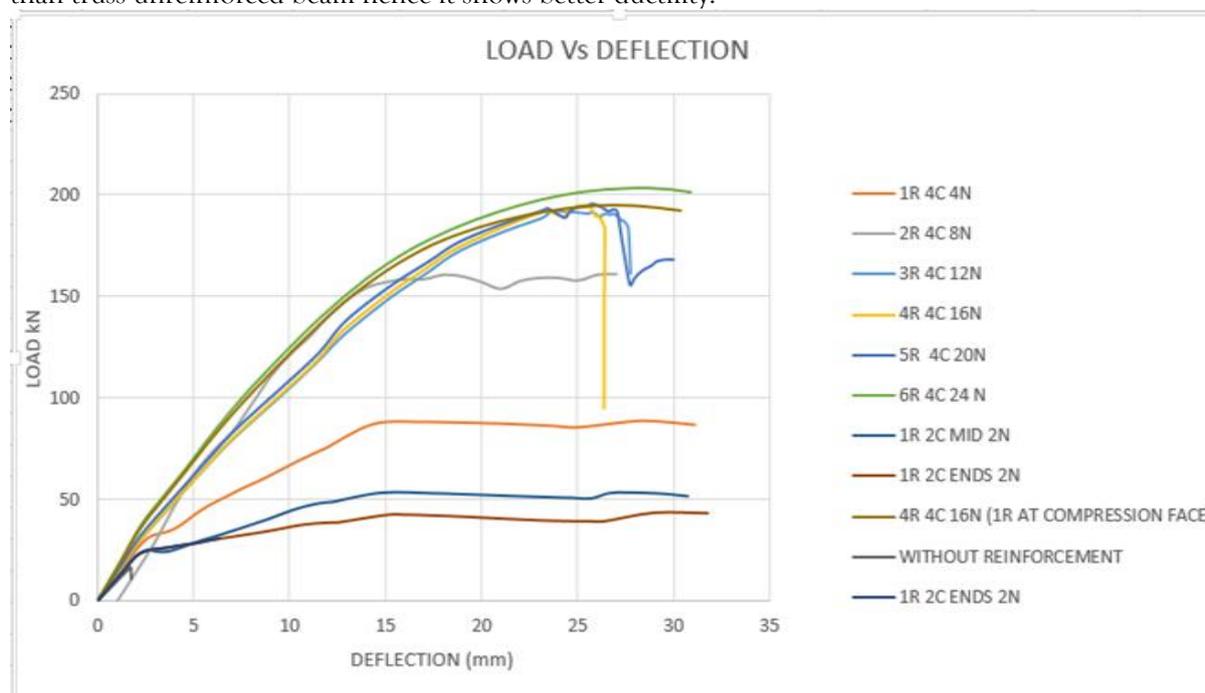

Fig 29: Load Vs deflection.

Table 7. Results of solid 3D printed beam with and without reinforcement

Table 8. Results of solid truss beam with and without reinforcement

Models	Deflection	Load	Percentage increase in load	Increase in load
Without reinforcement Solid 3d printed beam	1.73	16.414	1	1
1R 2C MID 2N	27.573	53.225	224.26559	36.811
1R 2C MID 2N	29.02	43.779	166.7174	27.365
1R 4C 4N	28.636	88.538	439.4054	72.124
2R 4 C 8N	30.249	161.05	881.1746	144.636
3R 4C 12N	24.12	192.33	1071.744	175.916
4R 4C 16N	25.393	194.81	1086.853	178.396
5R 4C 20N	25.673	195.68	1092.153	179.266
6R 4C24 N	27.582	203.24	1138.211	188.826
4R 4C 16 N (1R at compression face)	26.83	195.97	1091.92	179.556

Summary

In conclusion the optimum   placement of reinforcements in 3D printed beams significantly enhances their load bearing capabilities. When reinforcements are arranged in 3 rows and 4 columns, the beam exhibits remarkable strength, withstanding loads up to 192.33 kN. This represents a substantial improvement, being 10.71 times more resilient than conventional 3D printed beams.

Additionally, incorporating barbed wires in a configuration of 2 rows and 4 columns results in impressive load resistance, reaching a maximum displacement of 30.249 mm. The optimal performance is achieved with 8 to 12 barbed wires, demonstrating enhanced strength and ductility. Notably, a truss beam reinforced with 12 barbed wires outperforms a similarly reinforced solid 3D printed beam, showcasing a load-bearing capacity of 219.08kN.

The comparison between truss topology unreinforced beams reveals that the load-carrying capacity of the truss beam surpasses that of the unreinforced solid 3D printed beam by 10.196kN. In summary, the incorporation of barbed wires, especially in a quantity of 12, proves to be an effective strategy for achieving superior strength and ductility in 3D-printed truss beams.

REFERENCE LIST
1. Aramburu, A., I. Calderon-Uriszar-Aldaca., and I. Puente.: "3D printing effect on the compressive strength of concrete structures." Construction and Building Materials 354 -129108(2022).
2. Assaad, J. J., Abou Yassin, A., Alsakka, F., & Hamzeh, F.: A modular approach for steel reinforcing of 3D printed concrete—preliminary study. Sustainability, 12(10), 4062. (2020).
3. Gebhard, L., Esposito, L., Menna, C., and Mata-Falcón, J.: Inter-laboratory study on the influence of 3D concrete printing set-ups on the bond behaviour of various reinforcements. Cement and Concrete Composites, 133, 104660.
4. Han, X., Yan, J., Liu, M., Huo, L., and Li, J.: Experimental study on large-scale 3D printed concrete walls under axial compression. Automation in Construction, 133, 103993(2022)
5. Huang, S., Xu, W., and Li, Y.: The impacts of fabrication systems on 3D concrete printing building forms. Frontiers of Architectural Research, 11(4), 653-669(2022).
6. Hojati, M., Memari, A.M., Zahabi, M., Wu, Z., Li, Z., Park, K., Nazarian, S. and Duarte, J.P.:Barbed-wire reinforcement for 3D concrete printing. Automation in Construction, 141, p.104438 (2022).
7. Khormani, M., Jaari, V.R.K., Aghayan, I., Ghaderi, S.H. and Ahmadyfard, A.:Compressive strength determination of concrete specimens using X-ray computed tomography and finite element method. Construction and Building Materials, 256, p.119427 (2020).
8. Nguyen-Van, V., Nguyen-Xuan, H., Panda, B., and Tran, P.:3D concrete printing modelling of thin-walled structures.

In Structures (Vol. 39, pp. 496-511). Elsevier (2022).

9.   Rahul, a., and Santhanam, M.:Shantanu bhattacherjee. Indian concrete journal (2020).

10. Shahrubudin, N., Lee, T. C., and Ramlan, R. J. P. M.:An overview on 3D printing technology: Technological, materials, and applications. Procedia Manufacturing, 35, 1286-1296(2019).

11. Sun, X., Ye, B., Lin, K., and Wang, H.: Shear performance of 3D printed concrete reinforced with flexible or rigid materials based on direct shear test. Journal of Building Engineering, 48, 103860(2022).

12. Tinoco, M. P., de Mendonça, É. M., Fernandez, L. I. C., Caldas, L. R., Reales, O. A. M., and Toledo Filho, R. D.: Life cycle assessment (LCA) and environmental sustainability of cementitious materials for 3D concrete printing: A systematic literature review. Journal of Building Engineering, 52, 104456(2022)

13. Wang, L., Jiang, H., Li, Z., and Ma, G.: Mechanical behaviors of 3D printed lightweight concrete structure with hollow section. Archives of Civil and Mechanical Engineering, 20, 1-17(2020).