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LATTICIZING AXIALLY COMPRESSED MEMBERS IN TIMBER STRUCTURES: A METHOD FOR USING SMALL DIMENSIONAL LUMBER AS ALTERNATIVE TO MASS TIMBER PRODUCTS

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ABSTRACT: China's reliance on imported timber stems from the limited mechanical properties of domestic wood species, leading to the predominant use of mass timber products from imported wood in modern timber structures. To address this issue, innovative design approaches are needed to integrate domestically sourced timber into construction projects. This study explored the feasibility of using domestic wood species for small structural elements in axially compressed members as a potential alternative to mass timber products. The proposed latticization method, which integrates engineering mechanics with architectural design, aims to reduce material consumption and enhance structural stability and load-bearing capacity. This method's effectiveness was validated through a case study of Future City Experience Hall in Hangzhou, China, where its performance was evaluated in terms of structural safety, cost-effectiveness, and environmental impact. By demonstrating the sustainable use of local forest resources, this study contributed significantly to the design of axially compressed timber members, offering a pathway to reduce reliance on imported timber and minimize environmental footprint in China.

KEYWORDS: small dimensional lumber; axially compressed members; latticization method; domestic forest resource

1 – INTRODUCTION

China, the world's largest importer of timber, faces an expanding supply-demand gap that has increased its reliance on imported species [1]. Despite having abundant forest resources, including the world's largest man-made forest, the country continues to depend heavily on imported timber. This is due to limitations in the physical properties of domestic wood, which make it unsuitable for many construction projects [2]. Reducing this reliance is essential for promoting sustainability, which can be achieved by increasing the use of domestically sourced small-dimension timber. Such a shift would not only improve sustainable forest resource management but also ease the strain on timber imports.

As demand for timber structures increases in China, architects must balance material requirements with cost, sustainability, and constructability [3]. This necessitates innovative solutions to utilise domestic wood products and develop novel construction methods that maintain both structural integrity and efficiency [4]. This study explores the potential of domestically sourced small-dimension timber and proposes a design approach for transforming axially compressed members in mass timber into latticized components using locally sourced dimensional lumber, with the aim of enhancing their practical application in timber construction.

2 – METHODOLOGY

This study integrates engineering mechanics with architectural design to propose a latticization method for axially compressed members with aesthetically pleasing forms and structural soundness. The method consists of four stages. First, the design pressure value for the axially compressed member is determined. Second, the stressed section of the member is latticized to generate multiple design solutions. Third, the optimal latticized design is selected based on the proposed design principles. Finally, the selected solution is designed for detailing. This method is applicable to both new building design and building renovation scenarios: For new construction, the design pressure value of the axially compressed member can be derived directly through the finite element analysis (FEA) on the whole building structure; For building renovation, the minimum design pressure value of a single structural member will be calculated using the formula in the relevant technical standard, which serves as the basis for the subsequent latticization design.

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The above-mentioned method applies engineering mechanics in the first two stages, then employs the five architectural design minimization principles to evaluate and optimize solutions during the third stage. Ultimately, it synthesizes architectural design with engineering mechanics to develop latticized axially compressed members that achieve the aesthetical and structural integrity (Fig. 1).

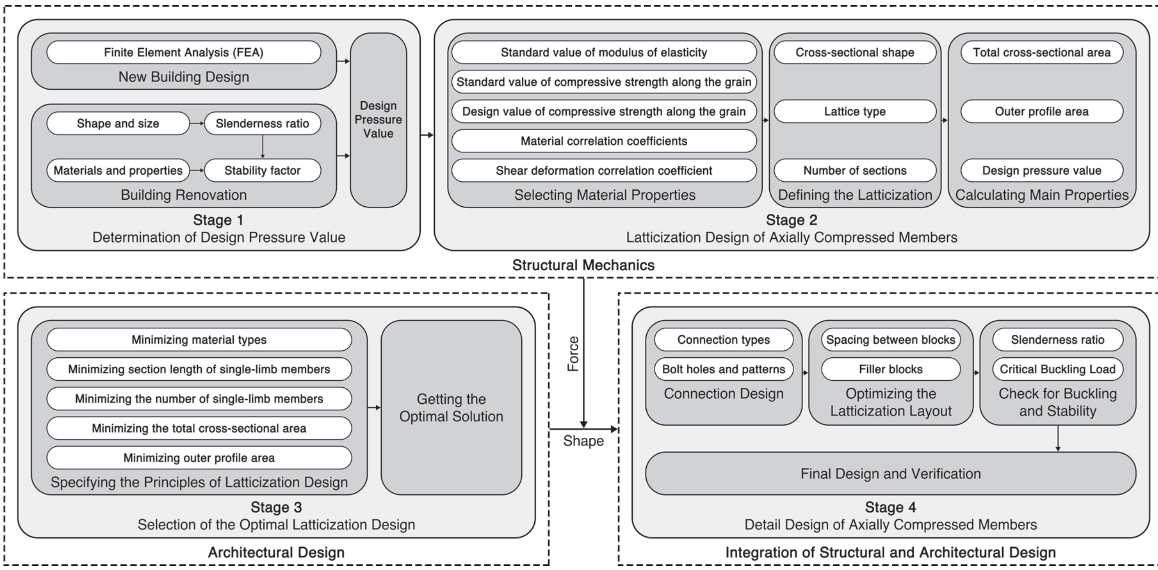

Figure 1. Research methodology

2.1 DETERMINATION OF DESIGN PRESSURE VALUE

To latticize axially compressed members using small wooden elements, the shape, size, materials, and physical properties of the members are required for the design pressure values in engineering mechanics. As previously stated, these values can be directly obtained through the entire structure's FEA in the case of new design. Here, the focus will be on a single structural member's latticization without knowing the entire building structure for FEA, especially in the case of building renovation. Therefore, the slenderness ratio (λ), stability factor (φ), and design pressure (N) of the original axially compressed members must be calculated. The relevant formulas and procedures are outlined in the *Standard for Design of Timber Structures (GB 50005-2017)* [5].

2.1.1 Calculation of Slenderness Ratio

$$i = \sqrt{\frac{I}{A}} \tag{1}$$

$$\lambda = \frac{l_0}{i} \tag{2}$$

where

A Cross-section area (mm^2);
I Cross-section moment of inertia (mm^4);
i Radius of gyration (mm);
l_0 Calculated length (mm);
λ Slenderness ratio.

2.1.2 Calculation of Stability Factor

$$\lambda_c = c_c\sqrt{\frac{\beta E_k}{f_{ck}}} \tag{3}$$

When $\lambda > \lambda_c$,

$$\varphi = \frac{a_c\pi^2\beta E_k}{\lambda^2 f_{ck}} \tag{4}$$

When $\lambda \le \lambda_c$,

$$\varphi = \frac{1}{1+\frac{\lambda^2 f_{ck}}{b_c\pi^2\beta E_k}} \tag{5}$$

where

f_{ck} Standard value of compressive strength (N/mm^2);
E_k Standard value of modulus of elasticity (N/mm^2);
a_c, b_c, c_c Material correlation coefficients;
β Shear deformation correlation coefficient;
φ Stability factor.

2.1.3 Calculation of Design Pressure Value

$$\frac{N}{\varphi A} \le f_c \tag{6}$$

Where

φ Stability factor;
A Cross-section area (mm^2);

f_c Design value of compressive strength (N/mm^2);

N Design pressure value (N).

2.2 LATTICIZATION DESIGN

Latticization shifts the center of gravity of a stressed section away from its axis of inertia to increase the member's moment of inertia and enhance its stability (Fig. 2). By placing the member away from the axis of inertia, it is possible to reduce the cross-sectional area and still meet the same load-bearing capacity requirements. Latticization of axially compressed sections effectively improves the component's buckling resistance by optimizing the structural distribution. According to the formulas outlined previously, when the stressed section is latticized into four smaller sections, distanced from both inertia axes simultaneously, the latticization design yields optimal results. Therefore, this study primarily adopts a latticization design comprising four quarter blocks.

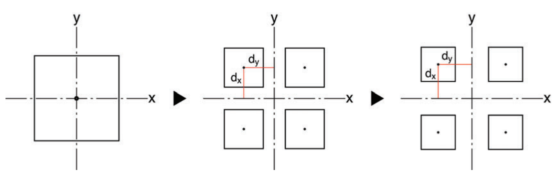

Figure 2. Latticization process

This study also proposes using domestically sourced larch dimensional lumber to replace imported mass timber in solid structural members. The available lumber's cross-sectional dimensions are standardized as follows [6] (Tab. 1):

Table 1: Size of China's domestic larch dimensional Lumbers

Size (mm)		
40×40	-	-
40×65	65×65	-
40×90	65×90	90×90
40×115	65×115	90×115
40×140	65×140	90×140
40×185	65×185	90×185
40×235	65×235	90×235
40×285	65×285	90×285

2.3 SELECTION OF OPTIMAL LATTICIZATION DESIGN

To optimize the latticization, architectural design factors must be considered, such as cost-efficiency, aesthetics, and functionality. The corresponding parameters include the cross-sectional shape and size of individual bars, the boundary for the cross-sections based on functional or structural requirements, and the assembly method, including the connections and end restraint conditions of the axially compressed members [7]. In order to select the optimal latticization design solution, the following five minimization principles are proposed to reduce material costs, minimize space occupation, and enhance structural efficiency:

1) Minimizing material types

Either using a single size of dimensional lumber or minimizing the lumber types simplifies design process, lowers costs and speeds up construction.

2) Minimizing section length of single-limb members

Shorter cross-section lengths are more readily available and have lower market prices. In addition, this reduces transportation and construction costs.

3) Minimizing the number of single-limb members

Reducing the number of single-limb members simplifies the structural design, improves material efficiency, and indirectly enhances stability.

4) Minimizing the total cross-sectional area

Minimizing the total cross-sectional area is crucial for achieving cost-effective and efficient construction.

5) Minimizing outer profile area

Excessive outer profile dimensions can compromise space efficiency, functional adaptability, and aesthetic quality.

2.4 DETAIL DESIGN OF AXIALLY COMPRESSED MEMBERS

Designing the cross-section alone is insufficient to ensure optimal performance of axially compressed members. Therefore, a comprehensive detailed design based on the selected solution is further required.

The first step in this design process is to determine the types and physical properties of the materials used. Next, the location and number of bolt holes must be specified. The quarter blocks are connected with bolts through the filler blocks, and to ensure reliable connections, the bolt

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holes are arranged in a staggered pattern according to the guidelines in the *Timber Structure Design Handbook* [8]. In addition to the connection design, the slenderness ratio of the quarter blocks, particularly in relation to the spacing between the filler blocks, is a critical factor. To meet the required slenderness ratio, the stability of the structural subunits can be improved by adjusting the number of filler blocks.

3 – LATTICIZATION METHOD APPLICATION AND RESULTS

In this study, Fuchunwan Future City Experience Hall, located in Fuchunwan New Area of Hangzhou, China, served as a case to verify the proposed latticization method for axially compressed members using China's domestic dimensional lumber (Fig. 3).

The building, designed by Jianxue Architecture and Engineering Design Institute, measures 63 meters in length, 35 meters in width, with a maximum roof height of 10.88 meters, covering a total area of 2,200 m². It is one of the largest modern timber structures in East China, using over 500 m³ of North American Douglas fir. The building features nine different types of columns, all made from glued laminated timber (GLT) with a strength grade of TC_T40. The dimensions and heights of the columns vary depending on their location within the building.

Figure 3: Fuchunwan Future City Experience Hall

3.1 DETERMINATION OF DESIGN PRESSURE VALUE

For this study, the columns in the hall's exterior corridor were selected for latticization. Specifically, the axially compressed members, i.e., the square columns, have a cross-sectional dimension of 380 × 380 mm and a height of 7,000 mm, which reflect the actual dimensions of the building's columns.

The material properties were sourced from *GB 50005-2017* [5]. The standard values for the modulus of elasticity (E_k) and compressive strength parallel to the grain (f_{ck}) are 10,400 N/mm² and 33 N/mm², respectively. The design value of compressive strength parallel to the grain (f_c) was taken as 23.2 N/mm² (Tab. 2). These material properties form the basis for the subsequent analysis and design calculations.

Table 2: Properties of Building Columns

Geometry		Value	Units
1	Section	380×380	mm
2	Height	7000	mm
Material Physical Properties		**Value**	**Units**
1	Standard value of modulus of elasticity (E_k)	10400	N/mm^2
2	Standard value of compressive strength parallel to the grain (f_{ck})	33	N/mm^2
3	Design value of compressive strength parallel to the grain (f_c)	23.2	N/mm^2

Based on the calculation method of the design pressure value for axially compressed members outlined in the former section, the design pressure for the original columns has been determined as 2445.09 kN (Tab. 3). This value represented the minimum design pressure required for the newly latticized axially compressed members to ensure both the structural safety and design efficiency.

The calculation results revealed that the slenderness ratio of the original column (63.8124) slightly exceeded the permissible limit (62.7586) for axially compressed members of this material. This justified the latticization of the column to reduce its slenderness ratio and enhance structural stability.

Table 3: Calculation of Design Pressure of Building Columns (N)

No.	Item		Value
1	Cross-section area	A	144,400 mm^2
2	Slenderness ratio	λ	63.8124
3	Limit value of slenderness ratio	λ_c	62.7586
4	Material correlation coefficients	a_c	0.91
		b_c	3.69
		c_c	3.45
5	Shear deformation correlation coefficient	β	1.05
6	Stability factor	φ	0.72986
7	Design pressure value	N	2445.09 kN

3.2 LATTICIZATION OF CROSS-SECTION

The material properties of the domestic larch dimensional lumber used in this study are detailed in Tab. 4. Here, a total of 36 latticization designs were focused on, which were derived by arranging and combining dimensional lumber with cross-sectional widths of 90 mm, 65 mm, and 40 mm, and lengths of 285 mm, 235 mm, and 185 mm (Tab. 5). All dimensional lumber with a cross-sectional length less than 185 mm was excluded during the design stage due to insufficient design pressure values or relatively large outer profiles, as determined by the calculations.

Table 4: Material properties of China's larch dimensional lumber

	Material Properties		Value	Units
1	Standard value of modulus of elasticity (E_k)		8600	N/mm^2
2	Standard value of compressive strength parallel to the grain (f_{ck})		22.5	N/mm^2
3	Design value of compressive strength parallel to the grain (f_c)		15.5	N/mm^2
4	Material correlation coefficients	a_c	0.91	-
		b_c	3.69	
		c_c	3.45	
5	Shear deformation correlation coefficient	β	1.05	-

These latticization designs were subject to the following three main prerequisite conditions (Fig. 4):

1) Since a beam with a width of 200 mm is supported on the original column, so a 200 mm wide space should be maintained between the dimensional lumbers in the direction of the y-axis in order to install the beam in between;
2) In order to simplify the latticization design and facilitate effective comparisons, the center of each quarter block was positioned 190 mm from the x-axis at the square end;
3) The ends of the latticized columns were assumed to be hinged.

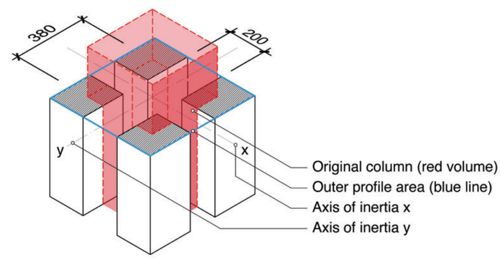
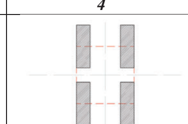
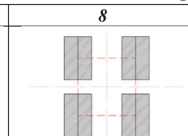
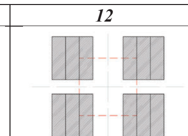
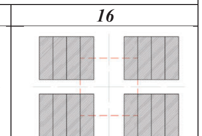
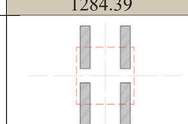
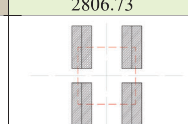
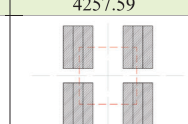
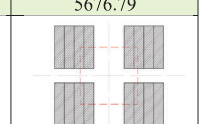


Figure 4. Prerequisite design conditions of latticization

3.3 SELECTION OF OPTIMAL LATTICIZATION DESIGN

Among the 36 types of the latticization designs, only 13 met the required load-bearing capacity for axially compressed members (Tab. 5). Of these, designs No. 12, No. 19, and No. 32 were selected for further consideration due to their smaller total cross-sectional areas, while the remaining 10 designs were excluded. Among these three candidates, design No. 19 stood out with fewer single-limb members and the smallest outer-profile area. Based on the five principles of latticization design described earlier and a comprehensive comparison, this design exhibited the best overall structural performance, utilizing 12 limbs of dimensional lumber with a cross-sectional size of 235 mm × 65 mm. Design No. 19 achieved an optimal balance of cost, strength, and stability, making it the preferred choice for the latticization of axially compressed members.

Table 5: 36 latticization designs using dimensional lumber

Cross-section			Properties	Number of Single-Limb Members			
L[1]	*W*[2]	*A*[3]		*4*	*8*	*12*	*16*
285	90	25650	Diagram				
				No.1	No.2	No.3	No.4
			Total Cross-Sectional Area	A×4=102600	A×8=205200	A×12=307800	A×16=410400
			Outer Profile	380×665	560×665	740×665	920×665
			Design Pressure Value (kN)	1284.39	2806.73	4257.59	5676.79
	65	18525	Diagram				
				No.5	No.6	No.7	No.8
			Total Cross-Sectional Area	A×4=74100	A×8=148200	A×12=222300	A×16=296400
			Outer Profile	330×665	460×665	590×665	720×665

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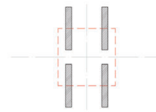
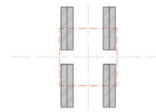
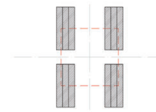
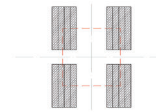
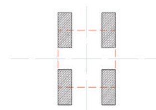
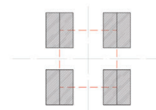
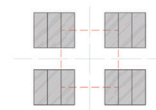
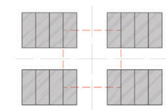
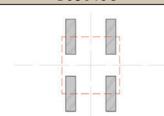
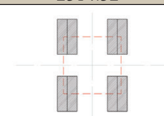
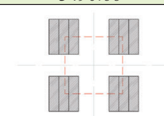
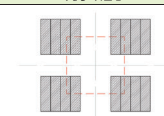
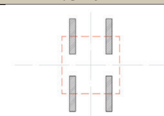
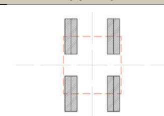
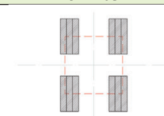
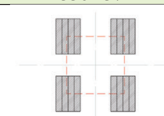
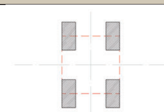
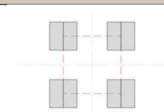
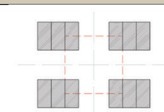
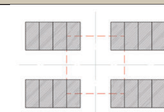
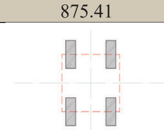
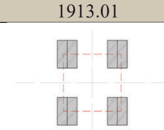
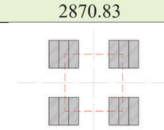
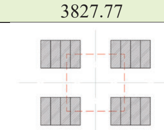
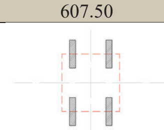
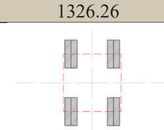
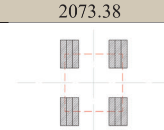
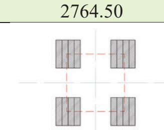
			Design Pressure Value (kN)	891.32	1945.87	3069.50	4099.90
	40	11400	Diagram				
				No.9	No.10	No.11	No.12
			Total Cross-Sectional Area	A×4=45600	A×8=91200	A×12=136800	A×16=182400
			Outer Profile	280×665	360×665	440×665	520×665
			Design Pressure Value (kN)	521.38	1124.84	1777.59	2459.16
235	90	21150	Diagram				
				No.13	No.14	No.15	No.16
			Total Cross-Sectional Area	A×4=84600	A×8=169200	A×12=253800	A×16=338400
			Outer Profile	380×615	560×615	740×615	920×615
			Design Pressure Value (kN)	1059.06	2314.32	3490.66	4654.21
	65	15275	Diagram				
				No.17	No.18	No.19	No.20
			Total Cross-Sectional Area	A×4=61100	A×8=122200	A×12=183300	A×16=244400
			Outer Profile	330×615	460×615	590×615	720×615
			Design Pressure Value (kN)	734.94	1604.49	2521.03	3361.37
	40	9400	Diagram				
				No.21	No.22	No.23	No.24
			Total Cross-Sectional Area	A×4=37600	A×8=75200	A×12=112800	A×16=150400
			Outer Profile	280×615	360×615	440×615	520×615
			Design Pressure Value (kN)	429.91	927.50	1465.73	2027.72
185	90	16650	Diagram				
				No.25	No.26	No.27	No.28
			Total Cross-Sectional Area	A×4=66600	A×8=133200	A×12=199800	A×16=266400
			Outer Profile	380×565	560×565	740×565	920×565
			Design Pressure Value (kN)	875.41	1913.01	2870.83	3827.77
	65	12025	Diagram				
				No.29	No.30	No.31	No.32
			Total Cross-Sectional Area	A×4=48100	A×8=96200	A×12=144300	A×16=192400
			Outer Profile	330×565	460×565	590×565	720×565
			Design Pressure Value (kN)	607.50	1326.26	2073.38	2764.50
	40	7400	Diagram				
				No.33	No.34	No.35	No.36
			Total Cross-Sectional Area	A×4=29600	A×8=59200	A×12=88800	A×16=118400
			Outer Profile	280×565	360×565	440×565	520×565
			Design Pressure Value (kN)	355.36	766.67	1211.57	1676.11

[1] L represents length of cross-section of single-limb member;
[2] W represents width of cross-section of single-limb member;
[3] A represents cross-sectional area of single-limb member.

Load-bearing capacity does not meet requirements;
Load-bearing capacity meets requirements;
Optimal design.

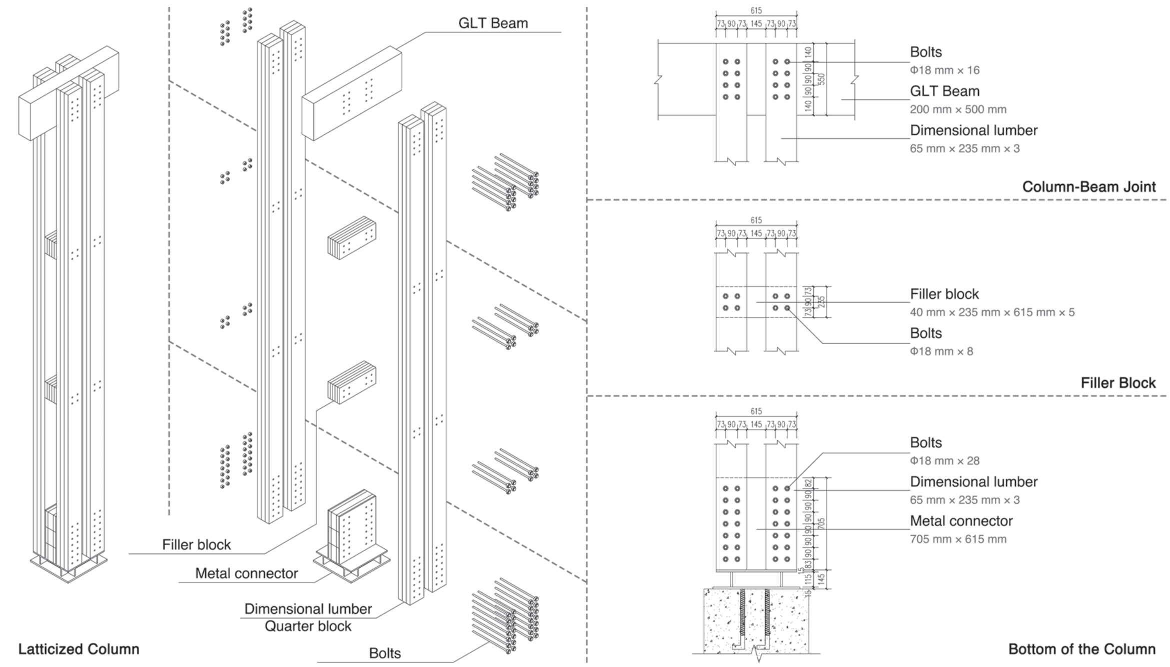


Figure 5. Detail design of latticized column

3.4 DETAIL DESIGN

Fig. 5 illustrates the detail design of the latticized column, which was developed in compliance with the relevant construction handbook [8]. Bolts with a diameter of 18 mm and a length of 590 mm were used uniformly throughout the structure. The filler blocks, made from the same lumber type, have a cross-sectional dimensions of 40 mm × 235 mm. From top to bottom, 16 bolts were used at the column-beam joint with a spacing of 90 mm. The edge distance was set at 140 mm for loads parallel to the grain and 72.5 mm for loads perpendicular to the grain. Eight bolts were used at the filler block position, and 28 bolts were placed at the bottom of the columns. The spacing and edge distances of the bolts were the same as at the head of the column and comply with construction requirements.

Additionally, the axial spacing between the beams, the two filler lumber blocks, and the column footing was set at 2130 mm. The slenderness ratio of a single quarter block was calculated to be 37.84, which fully satisfies the relevant design requirements, as it does not exceed the limit value of 73.017 for this material [5]. Both the slenderness ratio and critical buckling load for the quarter blocks are within safe limits.

4 – DISCUSSION

4.1 INTEGRATY OF FORCE AND SHAPE

This study combines engineering mechanics with architectural design to propose a latticization method for axially compressed members that ensures both structural integrity and aesthetic appeal. Specifically, the method integrates two key elements: *force* and *shape* (Fig. 6).

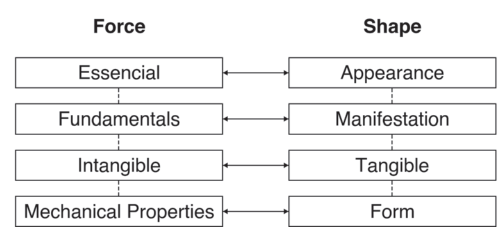


Figure 6. Force and shape in building design

Force represents the mechanical principles of structural engineering, which, though invisible, exert a real influence on structural rationality [9]. In contrast, *shape* pertains to the aesthetic and functional dimensions of architecture. Architectural design primarily focuses on the transformation and combination of shapes, utilizing geometric forms and other compositional methods to create form, with decisions based on architectural aesthetics and functional rationality [10]. These two elements are so inherently interconnected that one cannot

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be considered without the other, as they continuously inform and reinforce each other throughout the design and construction processes [11]. Architectural design must adhere to the fundamental principles of structural mechanics, where *force* and *shap*e must achieve balance [12]. A successful building design must seamlessly unite *force* (engineering mechanics) and *shape* (architectural design).

4.2 ADVANTAGES

Structural safety, cost-effectiveness, and environmental impact are critical factors that influence the success of building design. A comprehensive, multi-dimensional assessment of latticization design not only enables a thorough evaluation of its practical feasibility.

4.2.1 Structural Safety

Stability and load-bearing capacity are the core elements in evaluating latticization design. In this design, the stability factor of the axially compressed members has increased from 0.73 in the original columns to 0.89, marking an improvement of 22%. In terms of load-bearing capacity, the design pressure value for the axially compressed members has risen from 2445.09 kN to 2521.03 kN, an increase of approximately 76 kN. This improvement demonstrates the effectiveness of the latticization method in enhancing both the stability and load-bearing capacity of the structural components, thereby contributing to a more efficient and robust design.

4.2.2 Cost-Effectiveness

In this design, domestic timber species from China were utilized. The original column required 1.0108 m³ of GLT, while the latticized column in this design used 1.2831 m³, representing a 27% increase in timber consumption. However, considering the market prices of these materials in China, the cost of GLT with a strength grade of TC_T40 is approximately 15,000 RMB/m³, whereas the cost of domestic larch dimensional lumber is only 2,500 RMB/m³. The original column would cost around 15,200 RMB in lumber, while the latticized column would cost approximately 3,200 RMB, resulting in a savings of 12,000 RMB per column. This leaded to a total cost reduction of approximately 79% by using domestic timber. Such a significant decrease in material costs is particularly advantageous for large-scale construction projects, where material expenses are a key component of the overall budget.

4.2.3 Environmental Impact

The proposed latticization design offers significant environmental advantages, primarily due to the use of domestic timber resources, in contrast to the original design, which utilized imported Douglas fir from North America. By opting for locally sourced timber, the design reduced the carbon footprint associated with transportation, mitigated emissions from shipping and handling, and minimized waste from packaging and material supply chains. The use of domestic larch timber also supported local forestry industries and promoted the sustainable management of forest resources. Furthermore, by utilizing smaller timber dimensions, the design enhanced the efficiency of timber resource use, minimizing waste during both the manufacturing and construction phases. Overall, the adoption of domestically sourced materials in this latticization design fosters a more environmentally friendly construction process, supports local economies, and reduces the overall environmental impact.

4.3 LIMITATIONS

The proposed latticization method in this study has several limitations, particularly in terms of fire resistance. Although latticized columns enhance structural efficiency, they exhibit weaker fire resistance compared to solid columns, which, with their larger cross-sections, are better able to delay combustion.

To address this limitation, future research should prioritize improving the fire performance of timber structures. Potential strategies include the use of high-performance fire-retardant coatings and flame retardants, and the integration of fire-treated timber during manufacturing. Furthermore, incorporating fire protection measures such as sprinkler systems and fire alarms, along with comprehensive fire safety planning, including structural layout, ventilation, and escape routes, will further enhance the overall buildings fire safety.

5 – CONCLUSION

This study presented a novel latticization method for axially compressed members in timber structures, employing domestic larch dimensional lumber as an alternative to imported mass timber products. The application of this method in a real project demonstrated its potential to enhance structural stability and load-bearing capacity, reduce construction costs, and minimize environmental impact. By replacing larger timber members with smaller elements, the method preserved structural integrity while optimizing material usage. Additionally, it enhanced design flexibility, providing a practical and sustainable solution for modern timber construction.

6 – REFERENCES

[1] Y. Wang, Z. Zhu, and X Zhang. “Analysis of Macroscopic Layout and Utilization of China’s Timber Resources Based on Lorenz Coefficient.” In: Journal of China Forest Products Industry 60.5 (2023), pp. 82-87.

[2] H. Liu, et al. “Research Progress and Prospective of Glulam Space Frame Structures.” In: Journal of Hebei University of Engineering (Natural Science Edition) 39.4 (2022), pp. 1-11.

[3] T. Mandičák, et al. “Design of economic sustainability supported by enterprise resource planning systems in architecture, engineering, and construction.” In: Buildings 12.12 (2022), pp. 2241.

[4] A. M. Memari, et al. “Residential building construction: State-of-the-art review.” In: Journal of Architectural Engineering 20.4 (2014), B4014005.

[5] W. Long, et al. “Standard for Design of Timber Structures (GB 50005-2017).” National standard. China Architecture & Building Press, 2017.

[6] W. Liu. “Modern Timber Structures.” China Architecture & Building Press (2022), pp. 60-61.

[7] M. L. Gambhir. “Stability analysis and design of structures.” Springer Science & Business Media (2013).

[8] W. Long, et al. “Timber Structure Design Handbook.” Book. China Architecture & Building Press, 2021.

[9] F. D. K. Ching. “Architecture: Form, space, and order.” John Wiley & Sons (2023).

[10] K. Q. Lin. “Research on structure morphology collaborative design for digital architecture.” South China University of Technology (2020).

[11] S. M. Aygören, H. Türkdoğdu. “Forces, Structures, and the Evolution of Natural and Artificial Forms.” SETSCI-Conference Proceedings. Vol. 18. SETSCI-Conference Proceedings (2024), pp. 50-59.

[12] B. N. Sandaker, A. P. Eggen, M. R. Cruvellier. “The Structural Basis of Architecture.” Book. Routledge, 2019.

https://doi.org/10.52202/080513-0310