MULTIDISCIPLINARY APPLIED RESEARCH AND INNOVATION
e-ISSN: 2773-4773

MARI

Vol. 7 No. 1 (2026) 36-43
https://publisher.uthm.edu.my/periodicals/index.php/mari

The Development of Polylactic Acid (PLA) C-Channel Connector

Muhammad Hariz Iskandar Hairul Anuar[1], Nurhusna Ilyana Zakaria[1], Nurul Atiqa Najwa Atan[1], Khairi Supar[2]*

[1] *Department of Civil Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, Pagoh Higher Education Hub, 84600 Pagoh, Johor, MALAYSIA*

[2] *Geo-Structural Engineering and Technology, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, Pagoh Higher Education Hub 84600 Pagoh, Johor, MALAYSIA*

*Corresponding Author: khairis@uthm.edu.my
DOI: https://doi.org/10.30880/mari.2026.07.01.006

Article Info

Received: 1 October 2025
Accepted: 30 November 2025
Available online: 15 January 2026

Keywords

Modular Connector, C-channel Truss, 3D Printing, Fitment Test, PLA (Polylathic Acid), Sustainable Construction

Abstract

In this project, an innovative modular connector created especially for C-channel truss systems in construction is presented. Conventional installation techniques like welding, screwing, and manual alignment are time-consuming, frequently need skilled labor, and present safety hazards on the job site. In order to overcome these obstacles, a connector was created with AutoCAD software and manufactured via 3D printing using PLA (polylactic acid) material, which is renowned for its excellent dimensional correctness, durability, lightweight nature, and environmental sustainability. The connector offers structural versatility and ease of installation by supporting a variety of truss angle configurations, such as 90°-45°-45°, 126°-27°-27°, and 140°-20°-20°. Vernier calipers were used for dimensional verification in a fitment test to assess the connector's precision alignment and compatibility with typical C-channel profiles. The findings demonstrated that the connector provides a firm, secure fit without the need for sophisticated equipment or trained workers, thereby cutting down on assembly time and enhancing installation consistency overall. PLA is biodegradable, therefore using it not only makes the connector economical and recyclable, but it also encourages sustainable building approaches. This study offers enhancements in efficiency, structural performance, and environmental effect while illustrating a workable, secure, and scalable solution for contemporary construction needs. Additionally, it creates new avenues for future study into alternative thermoplastic materials, 3D printing integration into structural engineering applications, and modular joint design optimization.

1. Introduction

Structural efficiency and safe installation procedures have become critical issues in modern building, notably in the use of prefabricated components. Connectors in structural systems are used not only to join elements, but they also have a substantial impact on the stability and overall performance of the structure [1]. Lightweight structural components, such as aluminium-zinc C-channels, are popular in Malaysia due to their mechanical strength, corrosion resistance, and ease of manufacture. However, the lack of adaptive and modular connection mechanisms for these components creates practical issues during field installation. Traditionally, connections are made using welding, bolting, or hand fitting techniques that require specialized labor, exact alignment, and a significant amount of time on-site. These traditional methods frequently result in project delays, structural irregularities, and higher building costs [2]. Furthermore, relying on manual approaches increases the likelihood of human mistake and safety hazards, especially when applied to recurring jobs in complicated truss assemblies.

Recent improvements in digital fabrication, particularly additive manufacturing such as 3D printing, have opened up new possibilities for designing lightweight, custom-fit connectors. Materials like polylactic acid (PLA) provide appropriate mechanical qualities and dimensional precision for creating functioning prototypes, particularly for non-permanent structural systems [3]. The combination of digital design and fast prototyping technologies creates new opportunities for increasing efficiency, minimizing labour dependency, and improving structural consistency on building sites.

This study explores the creation of a modular connector system specifically designed to improve the assembly process for C-channel structural components. By addressing significant constraints in present connection procedures, the study hopes to contribute to more efficient, safer, and sustainable construction processes that align with continuing industrial transformation.

2. C-channel Connection

The building industry's quick development has raised demand for structural materials that are not only robust and long-lasting but also effective and versatile for a range of uses. Steel is still one of the most important of these, especially when it comes to the creation of trusses and structural systems. With a particular focus on C-channel trusses, their mechanical properties, connection techniques, and real-world applications, this literature review offers a thorough summary of earlier studies on structural steel components. This section attempts to provide a solid basis for comprehending the effectiveness, benefits, and drawbacks of utilizing C-channel profiles in contemporary construction methods by reviewing pertinent research.

Steel's strength, ductility, and durability make it a fundamental component of contemporary construction. Because of its exceptional resistance to stress and compression, this metal alloy which is mainly made of iron and carbon is perfect for a variety of structural elements, including trusses, beams, columns, and channel sections. Steel's capacity to be recycled and reused is one of its biggest benefits, since it promotes sustainability in building methods. Steel can also be produced into a variety of sizes and shapes, which increases design and construction flexibility. Steel continues to be the most commonly used building material, far outperforming substitutes like aluminium, with an annual global output of about 1.6 billion tons [4]. The popularity of steel stems from its relatively low production cost, the abundance of raw materials, and its exceptional versatility in a wide range of structural applications, from residential buildings to complex industrial frameworks.

Different profiles of structural steel are produced, each intended to serve a distinct purpose within a structural system. Because of its excellent load-bearing efficiency and resistance to bending and shear pressures, I-beams are among the most often utilized construction components. They are both economical and structurally sound because to their special cross-sectional design, which allows them to support wide spans with little material consumption [5]. In contrast, C-channels are lightweight and extremely rigid due to their open-faced shape. They are frequently used in industrial support structures, roof trusses, framing systems, and modular construction [6]. Steel columns serve as vertical load-transferring elements and are essential for maintaining the integrity and balance of high-rise structures. Available in various cross-sectional shapes, steel columns are engineered to resist compressive forces and can be adapted to various design needs [7]. Hot rolled steel is more malleable and easier to shape into large structural components, while cold rolled steel offers higher strength, superior surface finish, and dimensional accuracy, making it suitable for precision tasks [8].

C-channel connectors are widely used in structural applications due to their outstanding mechanical properties, which include stiffness, remarkable ductility, and high tensile and yield strength. These characteristics are essential for guaranteeing the durability and load-bearing capacity of truss structures. Mild steel C-channels are appropriate for medium-duty structural applications because of their tensile strengths, which range from 370 to 500 MPa. For outdoor or chemically demanding settings, stainless steel C-channels offer even greater tensile strength and superior corrosion resistance. Aluminium C-channels are lighter and offer a good balance between strength and malleability. These materials are chosen based on specific project requirements, including load conditions, environmental exposure, and budget constraints [9].

3. Methodology

This study adopts a structured and systematic methodology to ensure the development of the C-channel connector is carried out effectively. It begins with problem analysis and literature review to understand user needs and design challenges. This research intends to create a modular C-channel connector using a controlled and methodical methodology that begins with problem identification and a thorough literature evaluation. The first goal focuses on the design phase, which employs AutoCAD to create a comprehensive three-dimensional (3D) model of the connector. The next step is to fabricate the prototype, which includes establishing 3D printing slicing parameters and selecting (PLA) as the print material. The second goal focuses on precisely executing the 3D printing process to ensure an accurate and functional prototype. The final goal is to perform dimensional and fitting testing with Vernier calipers to validate crucial dimensions and check compatibility by building the prototype with actual C-channel sections. The study concludes with a set of recommendations derived from the testing outcomes, offering valuable insights for future improvements and broader applications in structural connection systems.

3.1 Connector Design

This connector is specifically designed to offer adaptability, precision, and ease of installation when connecting two C-channels in a cross configuration. Fig. 1 shows the connector's 3D design, which was rigorously built in AutoCAD to provide a precise and accurate picture of its structure and performance. It features strategically positioned screw points that ensure accurate alignment and enhance stability by minimizing unwanted movement after installation. The 3D model, developed in AutoCAD, provides a detailed and accurate representation of the connector, highlighting important aspects such as screw placement, spacing, and overall shape. This allows for early identification of design flaws and helps ensure the final product meets performance standards in real-world use.

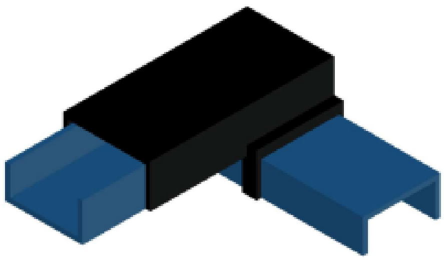


Fig.1 *Connector's design*

3.2 3D Printing

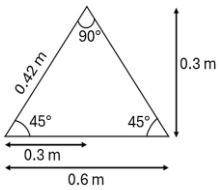
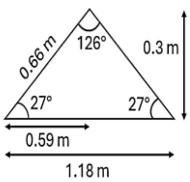
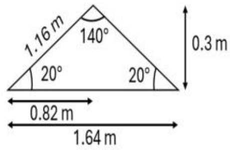
Fig. 2 illustrates the Ender 5 Max 3D printer used in this investigation to produce the connector samples. 3D printing, often known as additive manufacturing, is the method of creating three-dimensional objects using CAD or digital 3D models. This method includes depositing, connecting, or solidifying materials under computer control, usually layer by layer. The printing process begins with slicer setup, which involves configuring parameters such as layer height, infill pattern, print speed, and temperature. To avoid clogging or poor adhesion, physical preparations such as bed levelling, nozzle cleaning, preheating, and proper filament loading are conducted prior to printing. During printing, each layer is carefully inspected for flaws such as first-layer separation or nozzle obstructions. Advanced printers may incorporate camera systems to detect real-time anomalies and ensure consistent quality. Upon completion and cooling, post-processing steps such as support removal, surface finishing, and dimensional inspection are conducted to verify that the printed components meet the required tolerances and maintain the structural accuracy essential in additive manufacturing.

Fig. 2 *3D Printer*

3.3 Analysis of Symmetrical Truss Configurations

The analysis of triangular truss designs based on angle and ratio examines how alternative symmetrical arrangements affect structural performance. Three main designs 90°-45°-45°, 126°-27°-27°, and 140°-20°-20° were studied for their geometric features, height-to-base ratios, and angle distributions. These parameters have a direct impact on load-bearing efficiency, overall stability, and the amount of horizontal spread. Each arrangement has unique advantages based on the structural application, such as wide-span support or compact load distribution. Table 1 compares numerous triangular truss designs, illustrating how differences in angle combinations and height-to-base ratios affect their structural behaviour and applicability for specific applications. This analysis aids in the selection of the best truss design for specific engineering requirements, resulting in optimal performance and reliability in real-world building settings.

Table 1 *Analysis of Triangular Truss Designs Based on Angle and Ratio*

Angle of Truss			
Upper Connector	90°	126°	140°
Lower Connector (Right & Left)	45°	27°	20°
Height Ratio	1:1	1:2	1:3

The three symmetrical triangular truss designs have distinct structural advantages based on their angle and ratio arrangements. The first triangle, with a 90°-45°-45° angle, provides a balanced right-angled shape with equal sloping sides (0.42 m) and a 1:1 ratio (0.3 m height and base), making it perfect for vertical stability and even load distribution. The second triangle, with a 126°-27°-27° arrangement, has a wider base (1.18 m) and a 1:2 ratio, resulting in improved lateral stability and wider load distribution. The third and widest triangle (140°–20°–20°) has a 1.64 m base and a 1:3 ratio, suitable for structures requiring maximum base width and high horizontal load-bearing capacity.

3.4 Fitment Testing

Fitment testing is an essential technique used to assess the dimensional accuracy and assembly compatibility of 3D-printed components with standard industrial parts. In this study, it ensures that the 3D-printed C-channel connector fits precisely within actual C-channel profiles without requiring significant modifications. A successful fitment test confirms that the design tolerances established in the CAD software are accurately reproduced during the 3D printing process. This, in turn, demonstrates the reliability of additive manufacturing in producing components suitable for structural applications, where accuracy and consistency are vital.

4. Result and Discussion

The results of the design, 3D printing, and assessment procedures for the created C-channel connector are covered in this part. The study examines several truss configurations with an emphasis on dimensional accuracy, structural stability, and installation efficiency. The connector is easy to assemble, structurally stable, and suitable for use in contemporary modular construction systems, according to the test results. In practical engineering applications, accurate fitting is crucial for ensuring mechanical performance, structural integrity, and ease of assembly.

4.1 Specification of Prototype

A C-channel connector was successfully 3D printed using an Ender 5 Max and Ultimaker Cura, which both allow for exact control over factors like layer height and infill. Ultimaker Cura was chosen due to its ability to reliably produce dimensionally correct prints. The connector has an open center and vertical edges, resulting in a rectangular shape that fits securely around a typical C-channel. This design facilitates modular assembly by allowing structural joints, including a 90-degree prototype ideal for perpendicular connections, as shown in Fig. 3.

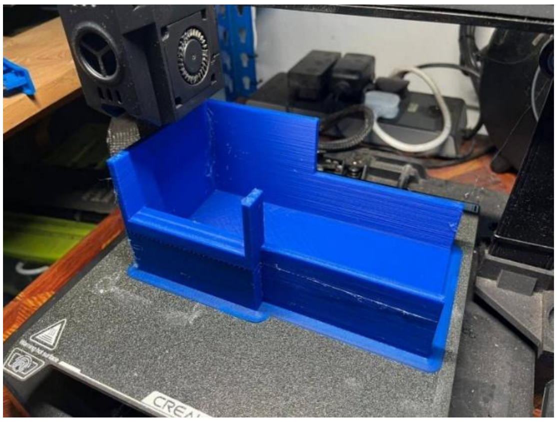


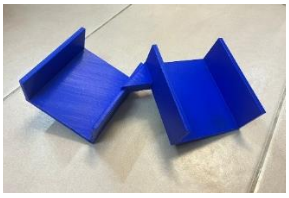
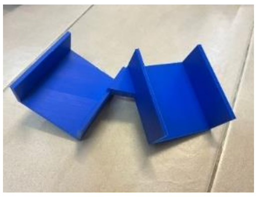
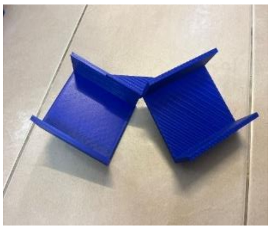
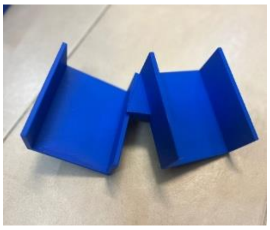
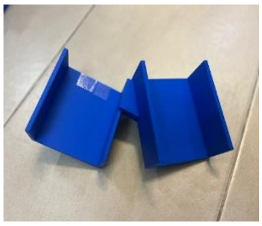
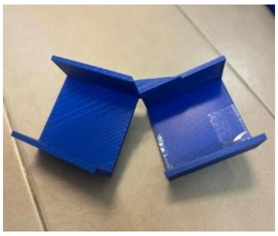
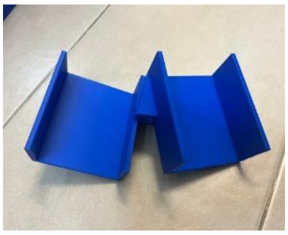
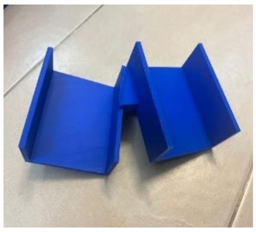
Fig. 3 *C-channel connector of 90° angle design*

Prototype the original CAD design was sliced and transformed into a printable model with Ultimaker Cura, which included brim and support features to maintain stability and prevent warping during the printing process. The connector's flat edges and crisp corners show that layer settings and print orientation were meticulously regulated to ensure dimensional precision. Its form and shape were specifically intended to fit typical C-channel dimensions, making it ideal for structural assembly systems, adjustable frame applications, and connecting modular building components.

4.2 Top-View Visuals of C-channel Connector Components

This section includes top-view images of the created PLA C-channel connector components utilized in this study. These photos show a clear representation of the finished product after 3D printing, allowing for visual verification of connector geometry, surface quality, and dimensional consistency. To exhibit adaptability in structural applications, the components were designed to accept a variety of truss angle configurations, including 90°-45°-45°, 126°-27°-27°, and 140°-20°-20°. Each connector set is photographed from above to confirm that form and alignment are correctly interpreted. These graphics are critical supporting data in determining the practicality and design integrity of modular connectors for real-world construction settings. Table 2 depicts the real top-view appearance of three distinct sets of modular PLA C-channel connectors built for different truss angle combinations.

Table 2 *Real Top-View Appearance of three distinct sets*

Set	Actual Design Product and Angle		
A			
	90°	**45°**	**45°**
B			
	126°	**27°**	**27°**
C			
	140°	**20°**	**20°**

Each set, labelled A, B, and C, consists of three interconnected pieces designed to fit precise structural angles. Set A shows a common triangle structure with angles of 90°, 45°, and 45°, which is appropriate for basic right-angle truss applications. Set B features a more asymmetrical configuration with 126°, 27°, and 27°, allowing for more creative structural layouts. Set C features a wide-span arrangement with angles of 140°, 20°, and 20°, which is excellent for larger load distribution applications. These top-view visuals clearly illustrate the dimensional consistency and clean edge finishing achieved through 3D printing, reinforcing the precision and practicality of the proposed connector designs for on-site construction applications.

4.3 Dimensional Analysis

A vernier caliper was used to measure the 3D-printed connector's dimensions in order to confirm that it was accurate in comparison to the original CAD design. The findings showed that the actual dimensions stayed within reasonable tolerance limits and closely matched the anticipated specifications. This attests to the printing method's accuracy and the prototype's dependability for practical use. Table 3 provides a thorough comparison of the connection and C-channel dimensions, which were obtained with a Vernier calliper for high accuracy.

Table 3 *Dimensional measurements of C-channel and Connector using Vernier Caliper*

Parameter	C-channel (mm)	Connector (mm)
Total Width	72.4	89.6
Real Dimension	0.8	5.2
Height (right)	38.0	45.1
Height (left)	34.7	41.1

The overall width, real dimension, and vertical heights on both the right and left sides of each component were the primary factors examined. The measurements show that the C-channel has an overall width of 72.4 mm, a right-side height of 38.0 mm, and a left-side height of 34.7 mm. In comparison, the connector has a total width of 89.6 mm, with a height of 45.1 mm on the right and 41.1 mm on the left. These dimension criteria are critical because they have a direct impact on the structural compatibility, assembly fit, and performance of the connection when connected to the C-channel.

4.4 Structural Testing Across Configurations

The 3D-printed connector was tested for its fitting performance in three triangular truss configurations: 90°-45°-45°, 126°-72°-27°, and 140°-20°-20°. Each design was evaluated based on dimension compliance, ease of installation, alignment precision, and structural stability, demonstrating the connector's versatility and dependability from all sides. The evaluation metrics for the 90°-45°-45° configuration, which is prevalent in symmetrical modular buildings, showed a height of 0.3 m, a base length of 0.58 m, a sloped side length of 0.65 m, and a height ratio of 1:1. These findings emphasize the connector's ability to preserve structural integrity while also allowing for easy assembly. The measurements for the remaining configurations are also specified, demonstrating the connector's versatility in various design scenarios and, ultimately, its constant performance across multiple truss designs. Table 4 shows the fitting performance metrics for three triangular truss configurations of 90°-45°-45°, 126°-72°-27°, and 140°-20°-20°, including measurements such as height, base length, sloped side length, and height ratio.

Table 4 *Fitting performance metrics for three triangular truss configurations*

Criteria	90°-45°-45°	126°-27°-27°	140°-20°-20°
Actual Illustration			
Height (m)	0.3	0.3	0.3
Base Length (m)	0.58	1.10	1.70
Sloped Side Length (m)	0.4	0.65	0.89
Height Ratio	1:1	1:2	1:3

Table 4 presents a full explanation of how each truss design meets the connector's standards. The 90°-45°-45° layout, which is commonly employed in modular constructions, has excellent metrics, indicating simplicity of installation and stability. In contrast, the other configurations demonstrate the connector's versatility by displaying diverse dimensional connections that retain structural integrity across multiple applications. This demonstrates the connector's ability to accommodate different design requirements while assuring dependable performance in truss construction.

5. Conclusion

Ultimately, this project demonstrates the successful use of 3D printing technology to design, fabricate, and test a modular C-channel connector. With precise digital modelling and the use of high-quality PLA material, the connector has demonstrated dimensional stability, ease of installation, and outstanding durability without the use of adhesives or fasteners. Test results show that it can adapt to a variety of truss angles and supports sustainable and flexible construction approaches. Future study recommendations include in-depth mechanical strength testing and design optimization using computer models, as well as field testing to gain significant practical insights. With these improvements, the C-channel connector has the potential to transform structural connection systems in the construction industry by making them faster, more efficient, and environmentally benign.

Acknowledgement

The authors would like to thank the Centre for Diploma Studies (CeDS), Universiti Tun Hussein Onn Malaysia for their continuous support. This project was made possible through the funding provided by grant K562 FGRS-EC, New Approach on the Performance Under Tensile and Compression Loading Conditions of Steel C-Channel Multi-bolted Joints.

Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Khairi Supar. Muhammad Hariz Iskandar bin Hairul Anuar;* ***data collection:*** *Nurhusna Ilyana Zakaria; Nurul Atiqa Najwa Atan* ***analysis and interpretation of results:*** *Muhammad Hariz Iskandar Hairul Anuar; Nurhusna Ilyana Zakaria, Nurul Atiqa Najwa Atan* ***draft manuscript preparation:*** *Nurhusna Ilyana Zakaria. Nurul Atiqa Najwa Atan All authors reviewed the results and approved the final version of the manuscript.*

References

[1] M. T. Naqash, A. R. Khan, and H. Yusuf, "*Connections are fundamental in structural engineering*," Journal of Structural Design, vol. 42, no. 3, pp. 210–225, 2024.
[2] J. Liu, Y. Chen, and Q. Wang, "*Traditional methods of structural connection and their limitations,*" International Journal of Civil Engineering Innovations, vol. 19, no. 2, pp. 145–158, 2018.
[3] T. D. Ngo, A. Kashani, G. Imbalzano, K. T. Q. Nguyen, and D. Hui, "*Additive manufacturing (3D printing): A review of materials, methods, applications and challenges,*" Composites Part B: Engineering, vol. 143, pp. 172–196, 2018.
[4] V. I. Lakshmanan, R. Roy, V. Ramachandran, *"Innovative process development in metallurgical industry,"* New York, NY: Springer, vol. 10, pp. 978-3, 2016.
[5] H. Patel, "I Beam Types, Key Features, Application, Advantages and Disadvantages," Brick & Bolt Home Construction, 2024.
[6] A. Habib, "Practical Analysis and Design of Steel Roof Truss According to American Standard," ClearsCalcs, 2023.
[7] G. Deepthi," Hot Rolled vs Cold Rolled Steel: A Comparative Analysis," Wevolver, 2024.
[8] M. A. Rahman, N. Ismail, and C. K. Tan, *"Mechanical characterization of structural connector materials for civil applications*," Journal of Materials Engineering and Performance, vol. 27, no. 5, pp. 2100–2108, 2018.
[9] J. H. Lee, and R. Kumar, "*Material selection strategies for lightweight and corrosion-resistant structural components,*" International Journal of Structural Materials, vol. 12, no. 3, pp. 145–153, 2020.