

**CARATTERIZZAZIONE GEOMETRICA DI STRUTTURE
RETICOLARI IN ACCIAIO REALIZZATE MEDIANTE
STAMPA 3D**

**GEOMETRICAL CHARACTERIZATION OF 3D PRINTED
DIAMOND LATTICE STEEL STRUCTURES**

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ABSTRACT

Additive Manufacturing (AM) technologies are opening new possibilities for fabricating complex metal geometries that are difficult to obtain through conventional processes. Among them, Wire Arc Additive Manufacturing (WAAM) has significant potential for civil engineering applications, owing to its suitability for large-scale steel components and high geometric freedom. This study focuses on Diamond Elements, a new class of lattice elements composed of Diamond unit cells with a regular polygonal base and inclined and vertical rods. These elements can be fabricated through the dot-by-dot WAAM strategy, based on the sequential deposition of molten metal droplets, and their manufacturing feasibility is demonstrated through WAAM-produced unit cells. Since this process may induce geometrical irregularities along rods and nodes, including local defects, discontinuities, lack of straightness and cross-sectional variations, geometric characterization is essential to assess printing quality and the severity of imperfections affecting structural and functional performance. A multi-level approach is therefore proposed, combining qualitative inspection and quantitative measurements. X-ray Computed Tomography and 3D scanning are adopted to reconstruct the as-built geometry and perform comparable measurements. Preliminary results from one

WAAM lattice unit cell are presented, including global dimensions, critical defect identification and hierarchical classification of rod and node regions, showing good geometrical accuracy.

SOMMARIO

Le tecnologie di manifattura additiva (AM) stanno aprendo nuove possibilità per la realizzazione di geometrie metalliche complesse, difficilmente ottenibili mediante processi convenzionali. In questo ambito, il processo Wire Arc Additive Manufacturing (WAAM) mostra un notevole potenziale per applicazioni nell'ingegneria civile, grazie alla possibilità di produrre componenti metallici di grande scala con elevata libertà geometrica. Il presente studio riguarda gli elementi Diamond, una nuova classe di elementi reticolari costituiti da celle unitarie Diamond, caratterizzate da una base poligonale regolare e da aste inclinate e verticali. Tali elementi possono essere realizzati mediante la strategia dot-by-dot WAAM, basata sulla deposizione sequenziale di gocce di metallo fuso. La fattibilità produttiva è dimostrata attraverso la realizzazione di celle unitarie prodotte mediante WAAM. Poiché questo processo può generare irregolarità geometriche lungo aste e nodi, quali difetti locali, discontinuità, mancanza di rettilineità e variazioni della sezione trasversale, la caratterizzazione geometrica è essenziale per valutare la qualità di stampa e la severità delle imperfezioni. A tal fine, viene proposto un approccio multi-livello che combina ispezione qualitativa e misurazioni quantitative. Tomografia Computerizzata a raggi X e scansione 3D sono impiegate per ricostruire la geometria as-built ed eseguire misurazioni confrontabili. I risultati preliminari, ottenuti su una cella unitaria reticolare prodotta mediante WAAM, evidenziano una buona accuratezza geometrica.

1 INTRODUCTION

Additive Manufacturing (AM) offers new opportunities for the fabrication of metal components with high geometric flexibility, reduced material use and tailored structural performance. Within steel structural applications, Wire Arc Additive Manufacturing (WAAM) has emerged as a suitable process for medium- to large-scale components, owing to its high deposition rate, efficient material use and ability to fabricate geometries that would be difficult to obtain through conventional manufacturing routes [1–3]. In particular, the dot-by-dot (DbD) WAAM deposition strategy enables the fabrication of rod-like elements through the sequential deposition of molten metal droplets, thus opening the possibility of manufacturing lattice structures composed of rods and nodes [4,5]. Within this framework, strut-based lattice configurations compatible with WAAM process constraints are considered [6]. Starting from FCC-based lattice topologies, a Diamond unit cell (D-cell) is defined as the elementary module of the proposed lattice system. Its periodic repetition along straight or curved spatial paths allows the generation of a novel class of steel lattice components, referred to as Diamond Elements (D-elements), whose geometrical configuration and structural behaviour are introduced in Section 2. The manufacturing activity, demonstrating the feasibility of WAAM for producing lattice structures, presented in Section 3, is part of the CIRCULAR WELD project [7], aimed at optimizing the WAAM process and the resulting printed components by assessing the relationship between process parameters and geometrical, microstructural and mechanical characteristics.

The focus of the present work is the geometrical characterization of WAAM lattice elements. To this aim, Section 4 presents a multi-level approach for evaluating geometrical irregularities and the severity of imperfections, which are fundamental aspects in the definition of the structural behaviour of WAAM elements. Section 5 reports the preliminary results obtained on one WAAM unit cell, including global dimensions, identification of critical defects and hierarchical classification of rod and node regions.

2 GEOMETRICAL CONFIGURATION AND STRUCTURAL BEHAVIOUR OF DIAMOND LATTICE ELEMENTS

Starting from the reference FCC and FCCZ lattice topologies [8], two types of D-cells were developed. The first configuration, referred to as the Diamond Frame cell (DF-cell) (Fig. 1a), is composed exclusively of inclined rods. This arrangement leads to combined axial compression and bending moments in the rods, resulting in a predominantly bending-dominated behaviour (Fig. 1d). The second configuration, referred to as the Diamond Truss cell (DT-cell) (Fig. 1b), combines inclined and vertical rods. In this case, compressive loads are mainly transferred through the vertical rods, governed primarily by an axial response, while the inclined rods act as bending-dominated connecting members (Fig. 1e). The choice between the DF-cell and DT-cell configurations is therefore related to the target structural behaviour. Their periodic repetition generates the corresponding Diamond Frame element (DF-element) (Fig. 1f) and Diamond Truss element (DT-element) (Fig. 1g).

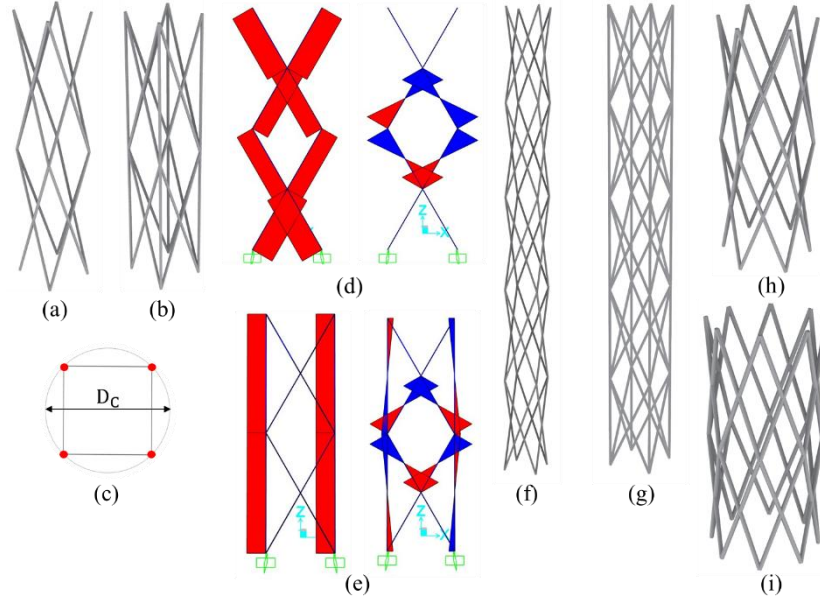


Fig. 1. Square-based (a) DF-cell and (b) DT-cell, with (c) corresponding polygonal base; structural behaviour of (d) DF-cell and (e) DT-cell, with axial force diagrams on the left and bending moment diagrams on the right; examples of square-based (f) DF-element and (g) DT-element; examples of DF-cells obtained by varying the polygonal base, namely (h) hexagon-based and (i) octagon-based configurations.

The geometry of each D-cell is defined from a regular polygonal base with (n) sides, inscribed in a circle of diameter D_c (Fig. 1c), and from the geometry of the Diamond chip (D-chip), namely the rhombus-shaped module on each face. The D-chip is defined by the rod inclination angle, the rod length (L) and the D-chip height (H_D). By varying these parameters, different families of D-cells can be generated for both DF- and DT-cell configurations, supporting a generative design approach (Fig. 1h,i).

3 FABRICATION OF DIAMOND LATTICE ELEMENTS

As part of the CIRCULAR WELD project [7], WAAM D-cells were manufactured to demonstrate the feasibility of DbD WAAM for realizing lattice-based geometries. Their fabrication builds on previous studies carried out within the same research framework, first addressing single rods and the calibration of process parameters to achieve geometrical repeatability and a reliable mechanical response, and subsequently focusing on nodal regions. In the latter studies, different intersection deposition strategies were investigated, leading to the selection of a single-droplet deposition strategy for the nodal region (Fig. 2a). This solution ensured a satisfactory mechanical response and node overstrength with respect to the rod region, resulting in failure occurring in the rods. Further details on these preliminary investigations are reported in Grossi et al. (2025) [5].

The specimens investigated in the present study were fabricated at the University of Florence (Fig. 2c). The WAAM setup and the process parameters adopted for their production are reported in detail in Grossi et al. (2025) [5,9]. During fabrication, the base plate was rotated so that, at each deposition step, the torch remained aligned with the rod axis and collinear with the gravity direction, ensuring consistent droplet stacking and geometric accuracy for both vertical and inclined rods. The adopted process parameters were a wire feed speed of 6 m/min, a deposition time of 0.6 s, a contact tip to work distance of 10 mm, and an idle time of 20 s between consecutive droplets. Both DF- and DT-cells were manufactured, for a total of six specimens. For this experimental campaign, both configurations had a square base and a rod inclination angle of 30° with respect to the vertical direction. The nominal rod diameter (d_n) was 6 mm, the rod length (L) was 40 mm, and the D-chip width (B) and height (H_D) were 40 mm and 69 mm, respectively, resulting in a total unit cell height (H) of 138 mm (Fig. 2b). The DT-cell shares the same geometry as the DF-cell, with the addition of vertical rods at the four corners of the square base.

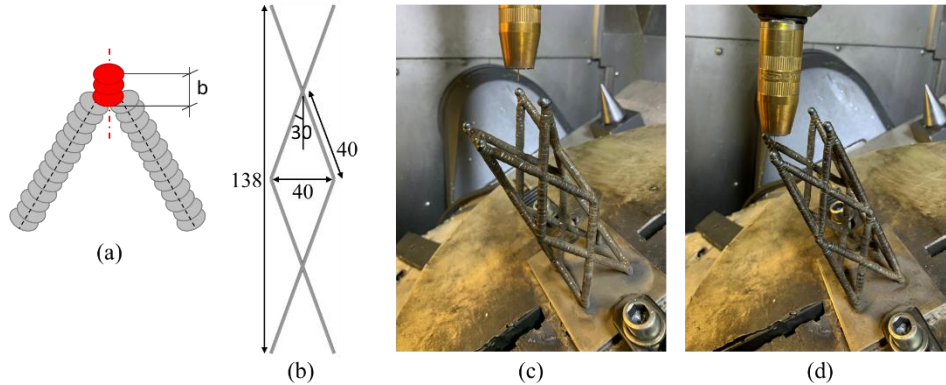


Fig. 2. WAAM fabrication and geometry of the investigated D-cells: (a) nodal deposition strategy; (b) 2D view of the DF-cell with the main geometric parameters, with lengths expressed in mm and angles in degrees; WAAM fabrication of (c) DF-cell and (d) DT-cell.

4 METHODOLOGY

The geometrical characterization of WAAM lattice elements is a key step for assessing printing quality and identifying deviations that may affect structural and functional performance. Owing to the DbD deposition strategy and to the presence of slender rods, nodal intersections and rod-to-node transition regions, these elements may exhibit local irregularities, cross-sectional variations, lack of straightness, material accumulation at nodes and deviations from the reference digital

geometry. For this reason, their characterization requires a procedure able to capture both the global geometry of the printed element and the local features of its constituent regions. To this aim, a multi-level approach is proposed for the geometric characterization of WAAM lattice elements, such as the D-elements introduced in Section 2. The procedure combines qualitative inspection and quantitative measurements, moving from the overall assessment of the printed geometry to the identification and classification of local geometric features in rod and node regions.

To consistently identify each local region, a specific alphanumeric nomenclature was adopted. Each label identifies the D-cell typology and number within the printed batch, the cell face or pair of faces, and the type and position of the considered region. The letters F and T refer to DF- and DT-cells, respectively, while L, P and N identify rods, planar nodes and non-planar nodes. For example, F1-1-L4 denotes rod 4 on face 1 of DF-cell 1, whereas F1-23-N1 denotes non-planar node 1 connecting faces 2 and 3 of DF-cell 1. This nomenclature allows rods and nodes to be unambiguously referenced during the subsequent analyses.

The approach is supported by two reconstruction techniques, namely X-ray Computed Tomography (CT) and 3D scanning, adopted to reconstruct the as-built geometry and perform comparable qualitative and quantitative measurements. CT enables the reconstruction of the volumetric geometry, allowing the analysis of internal defects, such as voids, linear indications and inclusions, and the extraction of external and internal surfaces for dimensional evaluation. According to ISO 15708:2025 [10], CT is defined as a relative technique, therefore, results obtained from the reconstructed volume should be compared with those derived from other measurement techniques. For this reason, 3D scanning is adopted as an additional technique for dimensional evaluation. The use of 3D scanning provides a three-dimensional surface mesh of the external geometry, which can be compared with the external surface extracted from the CT volume. The two reconstructed geometries are therefore used to analyse the actual morphology of the lattice elements, compare it with the reference digital model and assess the consistency between the two reconstruction methods.

4.1 COMPUTED TOMOGRAPHY

The as-built geometry of the WAAM lattice elements was reconstructed through X-ray Computed Tomography (CT), adopted as a non-destructive technique to obtain a three-dimensional volumetric representation of the printed specimens. The CT investigations were conducted at Sideius [11]. The CT setup consists of an X-ray source, a flat-panel detector and a rotational stage. During acquisition, the specimen is progressively rotated while 2D radiographic projections are collected. X-rays are attenuated according to the density and thickness of the crossed material, producing grey-scale images in which lower values are associated with air or voids, whereas higher values correspond to dense metallic material. The projections are then processed to reconstruct a 3D volume of voxels, each carrying a grey-scale value proportional to the local X-ray absorption. Finally, segmentation based on grey-scale histogram thresholding isolates the metallic phase from the surrounding air, yielding the reconstructed as-built geometry of the lattice element. In this case, micro-CT imaging was performed using a North Star Imaging X5000 system, equipped with a 240 kV microfocus X-ray source, filtered with 2 mm Cu, and a detector with a pixel size of 127 μm . Scans were performed by collecting 9004 projections in helicoidal mode at a voxel resolution of 70 μm . The reconstructed volume was then used for the defect analysis and the geometric characterization of the lattice elements, focusing on local thickness distribution and CAD comparison. The local thickness distribution was evaluated using a sphere-based method, in which thickness is defined as the diameter of the largest sphere fully inscribed within the solid volume at each position [12], making it suitable for WAAM lattice geometries characterized by curved surfaces, variable cross-sections and rod-to-node transitions. A CAD comparison was performed by comparing the reconstructed as-built volume with the corresponding reference digital model. This allowed the deviations between the

manufactured lattice element and the designed geometry to be quantified over the entire volume, supporting the identification of local dimensional inaccuracies and rod or node deviations.

4.2 3D SCANNING

The external geometry of the lattice elements was reconstructed through high-resolution 3D scanning [13]. The acquisition was performed using a hand-held structured-light scanner, namely the Artec Spider, based on a non-contact optical measurement technique commonly adopted for reverse engineering and dimensional control applications [14]. According to the manufacturer's specifications, the scanner has a 3D point accuracy of 0.05 mm [15]. The scanner operates by projecting a blue-light pattern onto the surface of the object. The surface morphology locally distorts the projected pattern, and these distortions are recorded by the camera integrated into the device. The three-dimensional geometry is then reconstructed through a triangulation-based procedure, allowing the external surface of the lattice element to be converted into a detailed digital mesh [16]. Because of the complex geometry of the lattice elements, specific precautions were required during acquisition. Slender rod-like regions, narrow diameters, nodal intersections and partially isolated branches may complicate both scanning and alignment of multiple acquisitions. For this reason, additional reference elements were introduced into the scene to provide background features and geometric continuity during scanning. The resulting high-resolution mesh provides the geometrical basis for subsequent measurements. From this model, local cross-sections can be extracted along rod and node regions, allowing cross-sectional areas, equivalent diameters and centroid positions to be evaluated. The sequence of centroids can also be used to describe the real axis of the rods as a polyline and to compare it with the corresponding ideal axis, while the reconstructed mesh can be compared with the reference digital geometry to quantify local deviations between the designed and manufactured lattice element.

4.3 MULTI-LEVEL APPROACH

The geometric characterization was conceived as a multi-level approach, structured into four consecutive levels of increasing detail (Fig. 3): (i) global dimensions, (ii) identification of critical defects, (iii) classification of rods and nodes, and (iv) refined measurements through 3D scanning. The rationale behind this procedure is to move progressively from the assessment of the overall correspondence between the printed element and the digital model to the local evaluation of geometrical features that may affect the structural performance of the WAAM lattice members.

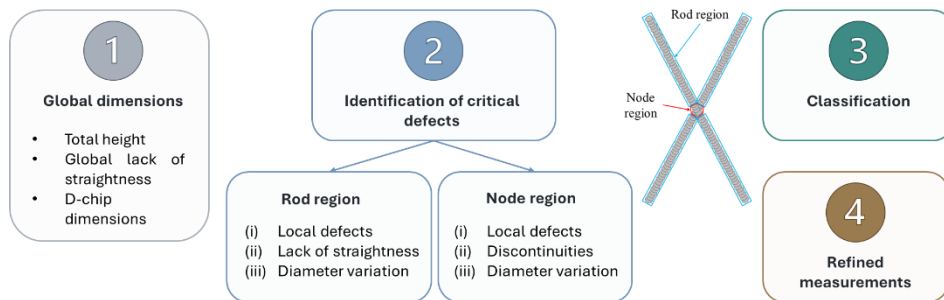


Fig. 3. Multi-level approach for the geometric characterization of WAAM lattice elements.

The first level concerns the global geometric characterization of the printed element. At this stage, the main geometrical dimensions are measured, including the distance between the lower and upper

plates (H_p), the D-chip width (B) and height (H_D), and the rod lengths (L). The global lack of straightness is evaluated as the deviation of the unit-cell axis from the vertical axis of the reference digital model. These measurements provide a first quantitative description of the manufacturing accuracy at the scale of the whole element.

The second level is devoted to the identification of critical defects on the CT reconstructed volume. For this purpose, the geometry is subdivided into rod and the node regions (Fig. 3). In the rod regions, the inspection follows a hierarchical sequence aimed at identifying: (i) local defects along the rod development (e.g., bubbles, dents); (ii) lack of straightness, evaluated as the distance between the ideal and real rod axis; (iii) diameter variation, defined with respect to the reference mean diameter of the cell (D_{mean}). The node regions are inspected according to the same logic, considering: (i) local defects on the node surface; (ii) discontinuities associated with incorrect convergence or divergence of the rods within the nodal region; (iii) diameter variations at the transition between rod and node regions.

The third level consists of the hierarchical classification of rods and nodes according to the presence and severity of the defects identified in Level 2 (Fig. 4). Each rod or node is assigned to one of three quality classes: high, medium or low. High quality is assigned when no critical defects are detected. Medium quality is assigned when limited defects or deviations are present but remain compatible with structural use, provided that their influence on the mechanical response is considered. Low quality is assigned when defects or deviations are sufficiently severe to make the member unsuitable for structural applications, requiring calibration of the WAAM process parameters to improve geometrical quality and repeatability. For rod regions, the presence of critical local defects leads directly to a low-quality classification. If no local defects are detected, lack of straightness is evaluated. High quality is assigned when the lack of straightness does not exceed 0.1 mm, according to values reported in previous studies [17]. Medium quality is assigned for values greater than 0.1 mm and not exceeding 0.2 mm, while values higher than 0.2 mm lead to a low-quality classification. Rods classified as high or medium quality in terms of lack of straightness are then assessed with respect to diameter variation. This parameter is evaluated by comparing the local diameter, obtained from the wall thickness analysis of the CT reconstructed volume, with D_{mean} . The rod is classified as high quality when the measured diameter remains within $D_{mean} \pm 0.2$ mm, where 0.2 mm corresponds to the standard deviation computed in previous studies [17]. A medium-quality classification is assigned when the diameter exceeds this range but remains lower than $D_{mean} + 0.4$ mm. Conversely, the rod is classified as low quality when the measured diameter is lower than $D_{mean} - 0.2$ mm, indicating a local restriction, or higher than $D_{mean} + 0.4$ mm, indicating an excessive enlargement. If the rod was classified as high quality in the lack-of-straightness check, the diameter-variation check directly determines the final class. If it was already classified as medium quality, it retains this class only when the diameter variation falls within the high-quality range, otherwise, the final classification is downgraded to low quality. For node regions, critical local defects or discontinuities lead directly to a low-quality classification. Nodes without local defects or discontinuities are then assessed in terms of diameter variation at the rod-to-node transition. In this case, the same criterion adopted for rod regions is used, and the diameter variation check determines the final node class as high, medium or low quality.

The fourth level consists of refined measurements through 3D scanning. After rods and nodes have been classified into the three quality classes, selected members representative of the high, medium and low quality categories are subjected to a more detailed geometrical investigation. Cross-sections are extracted along the rod and node regions, and the resulting geometrical data are compared with those derived from the CT-based classification. The final level therefore acts as a comparison step to validate the proposed classification procedure.

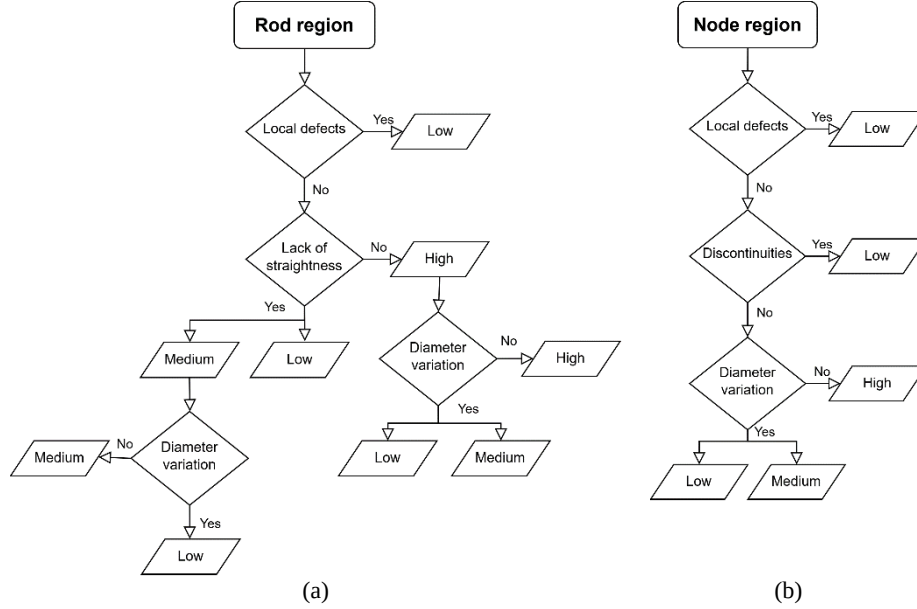


Fig. 4. Flowchart of the Level 3 hierarchical classification procedure for: (a) rod regions and (b) node regions.

5 PRELIMINARY RESULTS

Among the unit cells manufactured and presented in Section 3, CT and 3D scanning were performed on two selected specimens, one DF-cell and one DT-cell. This section reports selected preliminary results concerning the application of the proposed multi-level approach to the DF-cell fabricated through the DbD WAAM process. The aim is to show how the methodology can be implemented on a WAAM lattice element. For this purpose, the procedure described in Section 4.3 is applied from the first to the third level, including global dimensions, identification of critical defects, and hierarchical classification of rod and node regions. The fourth level, involving comparison with detailed geometrical data obtained from 3D scanning, together with the characterization of the DT-cell, will be addressed in future work.

5.1 FIRST LEVEL

The first level was applied to the DF-cell through a combined qualitative and quantitative assessment. The possible presence of global lack of straightness was first evaluated by visual inspection of the WAAM-produced DF-cell, shown in Fig. 5b, demonstrating no evident global lack of straightness. Manual calliper measurements were then performed on the same specimen to determine the main geometrical parameters of the unit cell, namely the distance between plates (H_p) and, for each face, the D-chip width (B) and height (H_D), and the rod lengths (L). The results are reported in Table 1 and organized according to the faces of the unit cell. For the rod lengths, the average value (L_{av}) is reported for each face (mean value $\pm$ one standard deviation). In addition, the table provides the average value over the whole unit cell for each measured geometrical parameter, comparing them with the nominal dimensions of the unit cell (see Fig. 2b) and shown in Fig. 5a. The comparison showed limited deviations from the nominal dimensions, with a reduction of

approximately 2% for the D-chip width, an increase of approximately 1% for the D-chip height, and a reduction of approximately 3% for the rod length. The corresponding coefficients of variation were 0.6%, 1.4% and 2.3%, respectively, indicating limited scatter among the measurements performed on the different faces of the unit cell. The comparison with the nominal value was not carried out for H_p , since the unit cell was welded to the top and bottom plates for subsequent mechanical testing. As a result, this distance is not representative of the actual total height of the unit cell and is necessarily smaller. Nevertheless, the coefficient of variation associated with H_p was equal to 0.7%, indicating a good parallelism between the two plates.

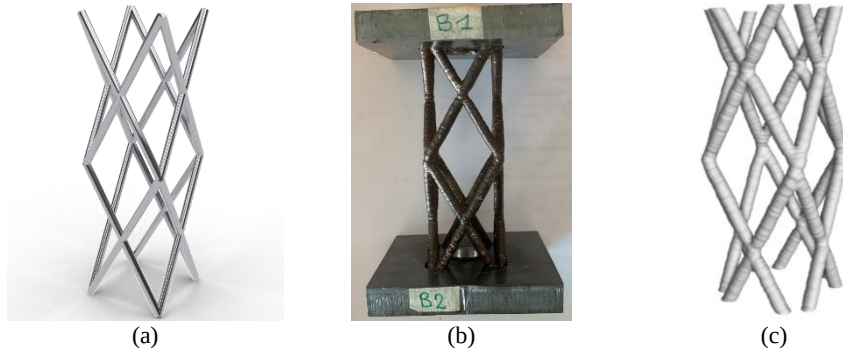


Fig. 5. DF-cell geometry: (a) digital model with nominal dimensions; (b) WAAM-produced specimen; (c) CT reconstructed volume.

Table 1. Geometrical parameters measured for the DF-cell within Level 1 of the multi-level approach.

Face	L_{av} [mm]	B [mm]	H_D [mm]	H_p [mm]
F1-1	39.0 ± 0.5	39.1	69.7	117.6
F1-2	38.0 ± 0.8	39.1	69.9	119.3
F1-3	38.6 ± 1.3	39.3	68.4	117.8
F1-4	39.1 ± 0.7	39.6	70.7	119.0
F1 Mean	38.7 ± 0.9	39.3 ± 0.2	69.7 ± 1.0	118.4 ± 0.9

5.2 SECOND LEVEL

The second level was applied to identify the critical defects defined in Section 4.3. The analysis was carried out on the CT volume (Fig. 5c) considering the rod and node regions separately. For the rod regions, no local defects were observed, and the CAD comparison did not reveal an evident lack of straightness. The wall thickness analysis provided a mean cell diameter (D_{mean}) of 5.61 mm, with a standard deviation of 0.14 mm, validated through manual calliper measurements. Although this value is approximately 6.5% lower than the nominal diameter of 6 mm, it is consistent with the results obtained in a previous study on two-way planar and non-planar intersection rods [7]. For the node regions, no local defects or discontinuities were identified. Diameter variation was assessed from the wall thickness analysis by comparing the local values with D_{mean} , according to the criterion defined in Section 4.3.

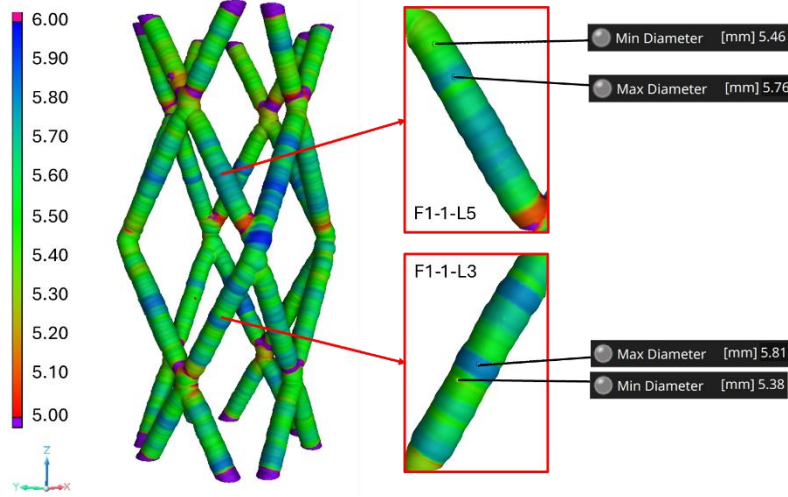


Fig. 6. Wall thickness analysis of the DF-cell: on the left, colour-map representation of the thickness distribution on the CT volume; on the right, close-up view of two representative rods with indication of the minimum and maximum diameters along the rod axis.

5.3 THIRD LEVEL

In the third level, the hierarchical flowcharts presented in Fig. 4 were applied to classify the D-chip rods and non-planar nodes into the three quality classes defined in Section 4.3. The classification was based on the critical-defect identification performed in the second level and followed the hierarchical sequence of checks defined for each region (Fig. 4). For the rod regions, the flowchart reported in Fig. 4a was applied. Since no local defects were observed and no evident lack of straightness was detected in the second level, the classification was governed by the diameter-variation check. The local diameter values obtained from the wall thickness analysis were compared with D_{mean} , equal to 5.61 mm, and each rod was assigned to the corresponding quality class according to the thresholds defined in Section 4.3. Rod F1-1-L5 is reported as a representative high-quality case. No local defects were observed and, based on the CT volume together with a preliminary visual inspection of the CAD comparison, the lack of straightness was lower than 0.1 mm, corresponding to the high-quality range. The local diameter was then evaluated by identifying the minimum and maximum values along the rod axis from the wall thickness analysis (Fig. 6), which were equal to 5.46 mm and 5.76 mm, respectively. Since both values remain within the $D_{\text{mean}} \pm 0.2$ mm range, rod F1-1-L5 was classified as high quality. Rod F1-1-L3 is reported as an example of low-quality classification. Also in this case, no local defects or evident lack of straightness were detected, however, the minimum diameter was equal to 5.38 mm, which is lower than $D_{\text{mean}} - 0.2$ mm, corresponding to 5.41 mm. The rod was therefore classified as low quality because of a local restriction of the cross-section. For the non-planar node regions, the flowchart reported in Fig. 4b was applied. Since no local defects or discontinuities were detected in the second level, the classification was governed by the diameter-variation check at the rod-to-node transition regions. The local diameter values were compared with D_{mean} , according to the same criterion adopted for the rod regions. The complete classification of D-chip rods and non-planar nodes is reported in Table 2.

Table 2. Classification of D-chip rods and non-planar nodes according to the Level 3 hierarchical procedure.

Region	High	Medium	Low
Rod	F1-1-L5	F1-2-L6	F1-1-L3
	F1-2-L4	F1-3-L3	F1-1-L4
	F1-2-L5	F1-3-L5	F1-1-L6
	F1-3-L4	F1-3-L6	F1-2-L3
	F1-4-L4	F1-4-L6	F1-4-L3
	F1-4-L5		
Non-planar node	F1-41-N1	F1-12-N1	F1-23-N1 F1-34-N1

6 CONCLUSIONS

The present work introduced a multi-level approach for the geometrical characterization of WAAM-fabricated lattice D-elements. The main contribution lies in the use of X-ray Computed Tomography for the geometrical characterization of WAAM lattice elements, combining qualitative inspection and quantitative measurements. The approach comprises four consecutive levels of increasing detail: global dimensional assessment, critical-defect identification, hierarchical classification of rod and node regions, and refined measurements through 3D scanning. Preliminary results were presented for one WAAM-produced DF-cell, applying the methodology up to the third level, namely classification. The investigated DF-cell showed good geometrical accuracy. Level 1 measurements indicated limited deviations from the nominal geometry, with low coefficients of variation for D-chip width, D-chip height and rod length. At levels 2 and 3, no local defects or evident lack of straightness were identified in the rod regions, and no local defects or discontinuities were observed in the node regions. The wall thickness analysis performed on the CT reconstructed volume provided a mean diameter of 5.61 mm, approximately 6% lower than the nominal value of 6 mm and consistent with previous observations on WAAM-produced two-way planar and non-planar intersection rods. Based on diameter variation, 70% of the D-chip rods and 50% of the non-planar node regions were classified as high or medium quality. These results confirm the relevance of a dedicated geometrical characterization for WAAM lattice elements, in which critical defects must be evaluated using criteria tailored to the different regions of the cell. The observed local diameter variations also highlight the need to calibrate WAAM process parameters specifically for rod, node and rod-to-node transition regions. Since CT is defined as a relative technique, the results obtained from the reconstructed volume were validated through comparison with manual calliper measurements. Future work will complete the fourth level of the multi-level approach through comparison with 3D scanning results and will extend the methodology to DT-cells.

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KEYWORDS

Design for Additive Manufacturing, Lattice Structures, Steel Structures, Wire Arc Additive Manufacturing, Geometrical Characterization, Computed Tomography, 3D Scanning.