Repeatability of robotic WAAM geometric properties for aluminum printing

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Introduction

Wire arc additive manufacturing (WAAM) is a direct energy deposition (DED) additive manufacturing (AM) process that is becoming increasingly implemented in production environments. WAAM utilizes gas metal arc welding to deposit metal in a layer-by-layer process. WAAM can produce large complex geometries that are traditionally produced by casting or forging. There is currently a lack of US infrastructure for traditional manufacturing methods and lengthy lead times for offshore production which promotes the commercialization of WAAM. WAAM has potential to be a mainstream manufacturing process, but it must exhibit sufficient accuracy and repeatability for production requirements. This study evaluates ~~the~~ geometric repeatability by printing a single geometry five times while maintaining the same part plan, weld settings, and wire. Each component is measured, comparisons are performed, and conclusions are drawn.

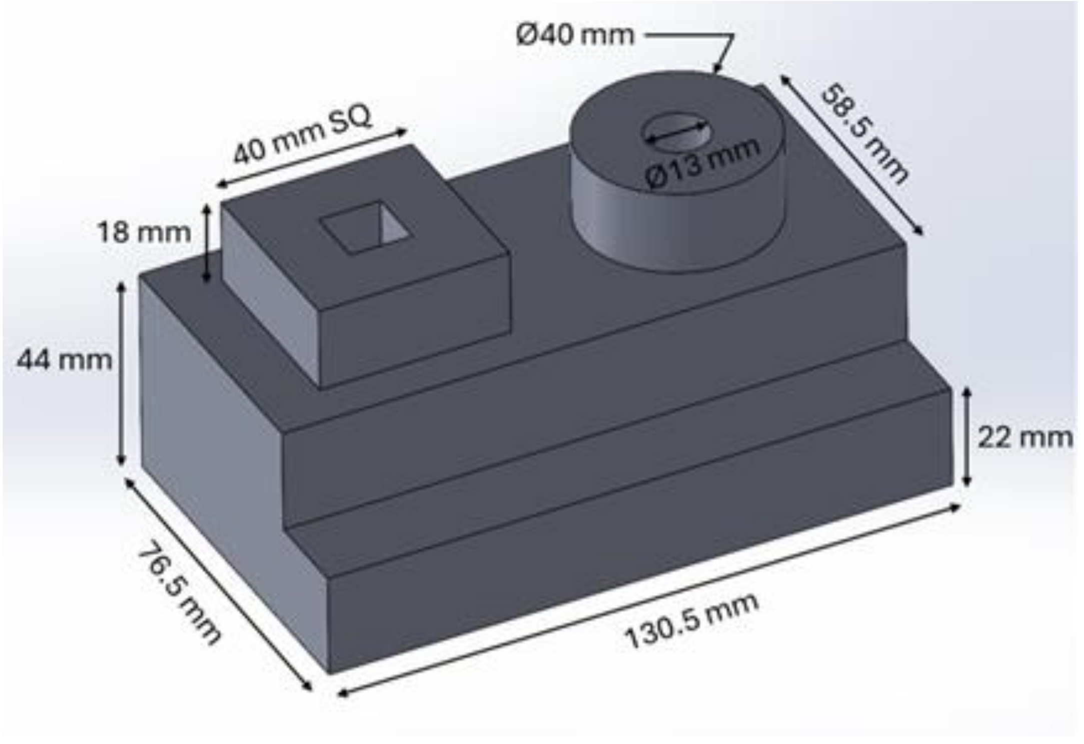
Aluminum robotic WAAM

This study uses a KUKA KR 50 R2500 robot and a Fronius CMT Advanced 4000 welder. ER4943-aluminum wire with a diameter of 1.2 mm is used to deposit the part geometry. The synergic line (i.e., the factory-programmed parameters) used for this deposition is Cold Metal Transfer (CMT) Advanced.

	Current (A)	Voltage (V)	Wire feed rate (m/min)	Travel speed (mm/s)
First Layer	158.0	15.3	8.0	10.0
Other Layers	149.0	15.1	7.5	10.0

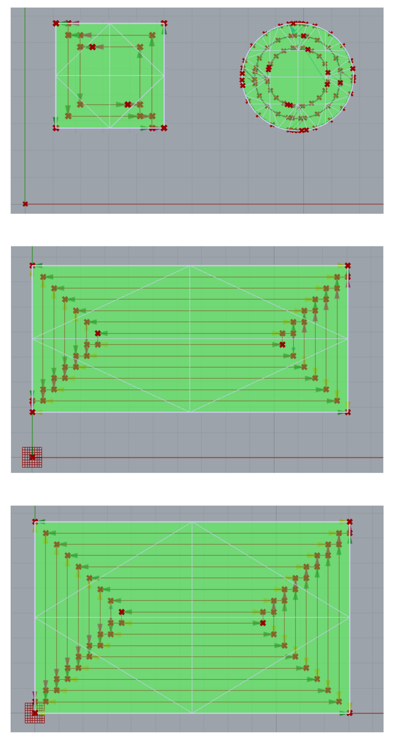
Nominal CAD model

The CAD model contains multiple geometric features that make up the component, including a lower and upper stair as well as a cuboid and cylinder on the upper stair surface. The CAD model acts as the nominally dimensional accurate representative.



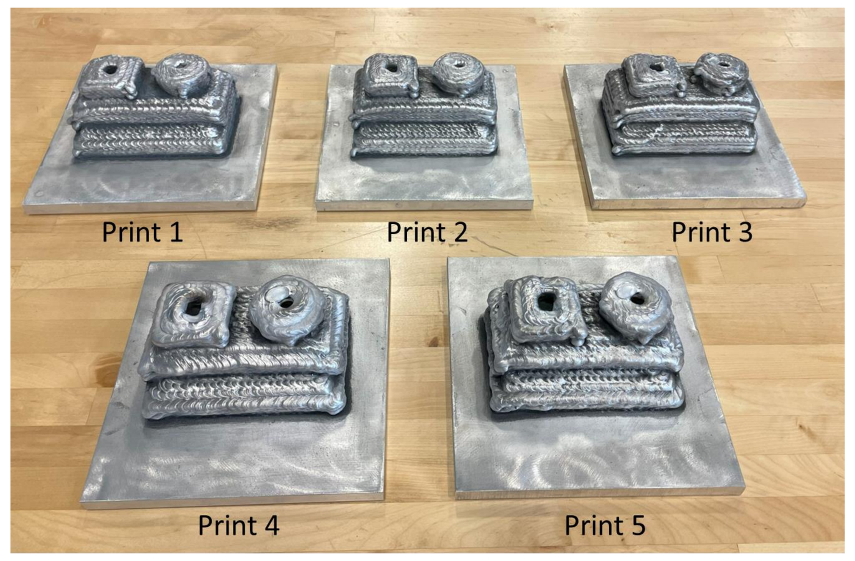
Path planning

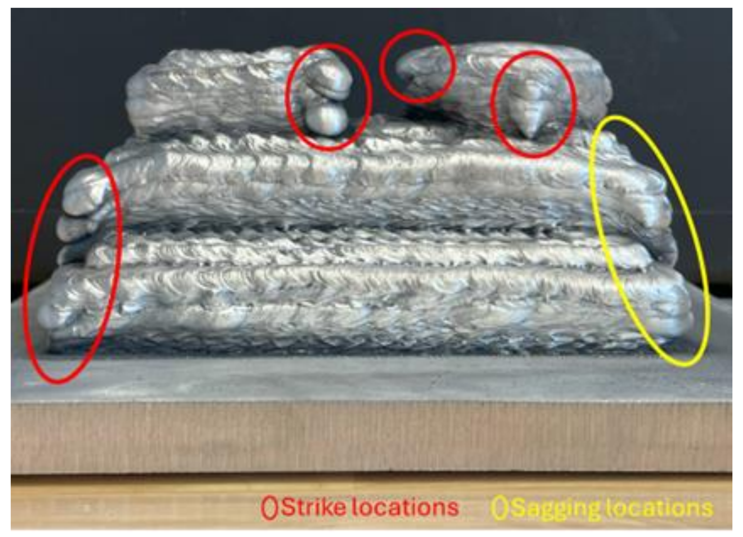
Using Rhinoceros 7 and the Grasshopper plug in, a spiral path was selected for the robot motions [1]. Each geometric feature initiates the strike of the arc at the outer wall and the crater finishes in the middle of the component following the spiral. For the stair steps, the spiral switches direction for each layer. The spiral path was used to provide a relatively uniform temperature distribution, and minimizes the strike and crater zones.



Printed components

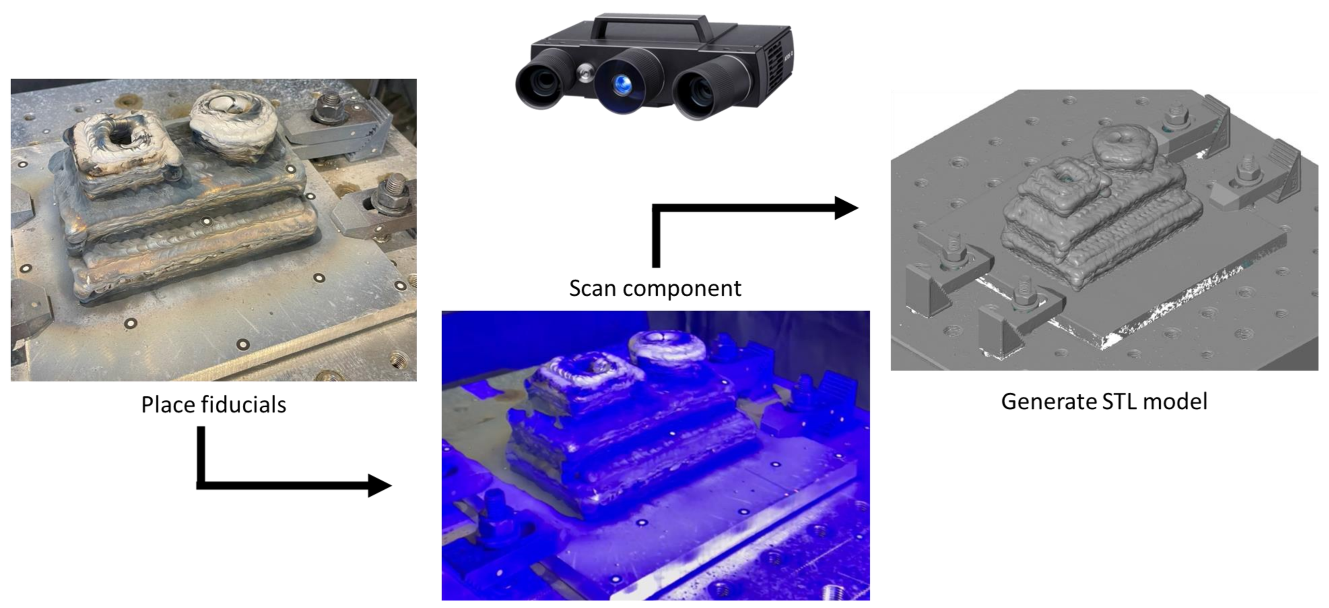
Each geometric feature was printed for all five components. Surface defects, such as buildup at the strike location of each layer, can be observed in all prints. To ensure full penetration, there is more material deposited at the strikes. This results in surface defects with a sagging nature from the effect of gravity on the extra deposited material.





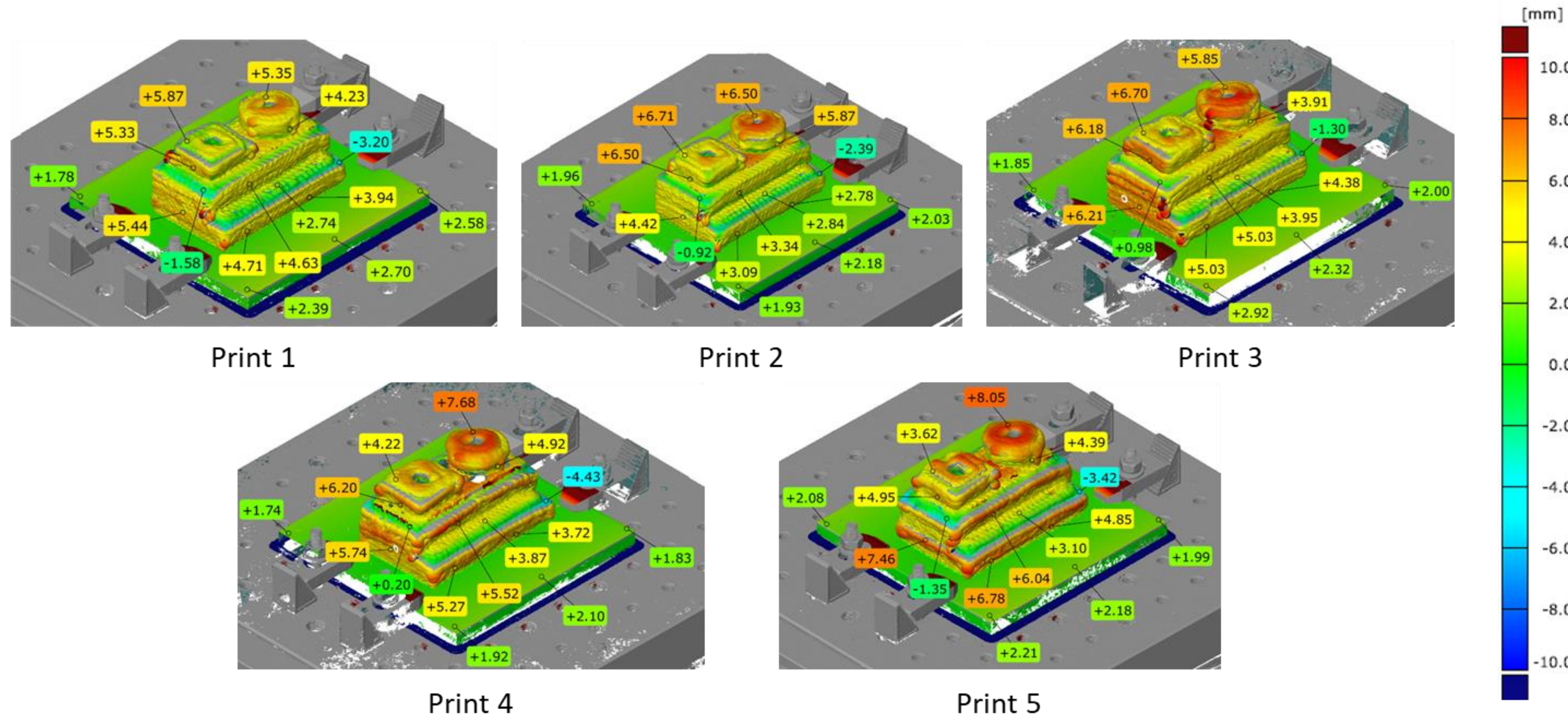
GOM structured light scanning

Using a GOM ATOS Q, an STL model is created for each print by projecting a known pattern onto the print, taking images of the print and stitching the images together[2]. Each STL model is aligned to the nominal CAD model by a "best fit" alignment algorithm. Then all prints are compared to the nominal CAD model and to each other to measure the accuracy and repeatability of the aluminum WAAM process.

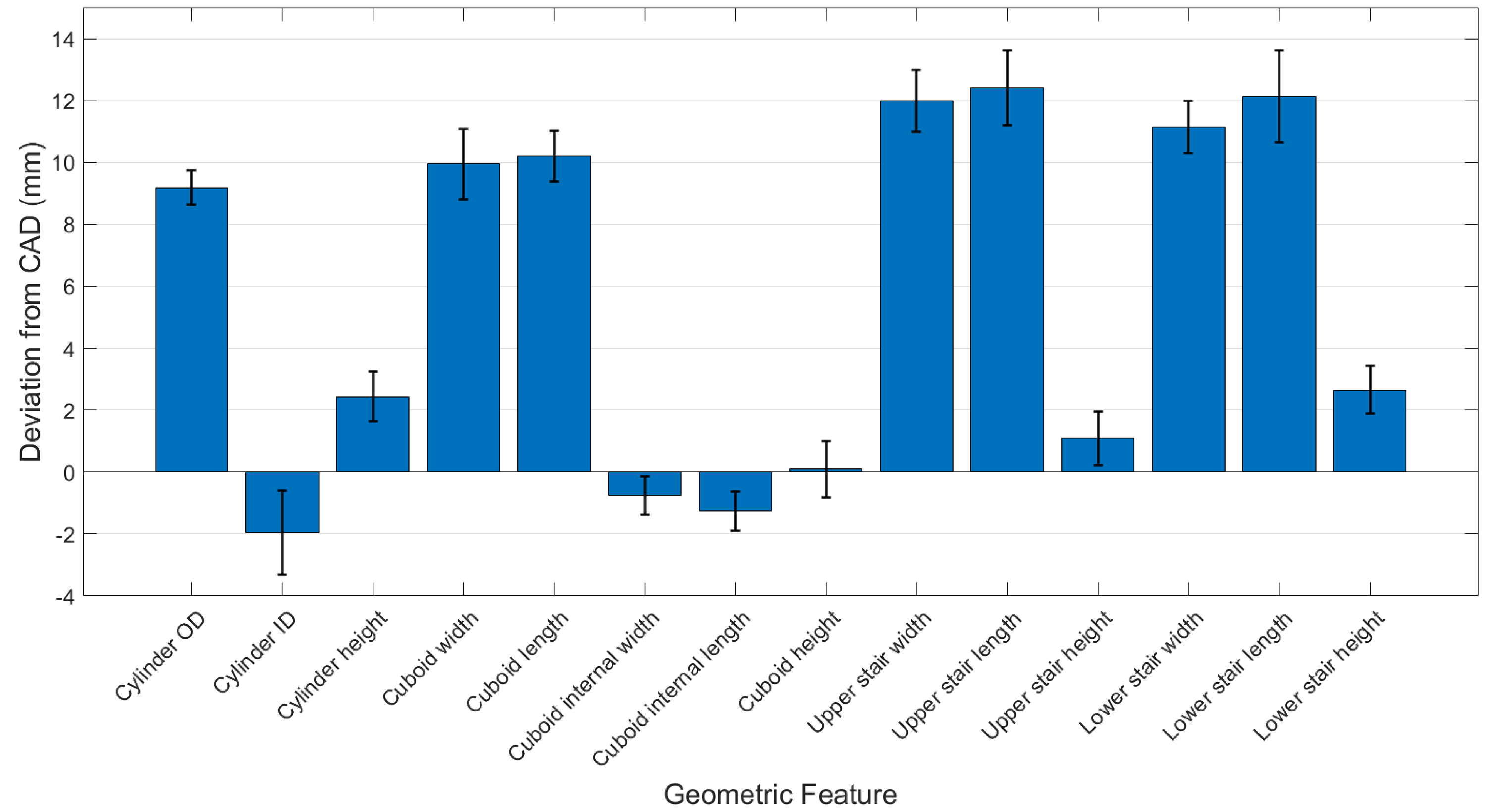


Results and conclusions

Using a surface comparison on a scale from -10 mm to 10 mm, each part is compared to the nominal CAD model. Slight differences between each print are observed, but follow similar trends in most locations. This shows that each print is repeatable with only slight deviations from one to the next.



The accuracy and precision of the printed components are seen in the bar graph below. The bars identify the accuracy of the process relative to the CAD model. The bars show that each geometric feature was overbuilt when compared to the CAD model. The error bars identify the process repeatability. These show that there are slight deviations in all the geometric features from one print to the next. The average value of all standard deviations was 0.93 mm, which indicates that the print repeatability is small, relative to the resolution of the WAAM process, and the process is reasonably precise.



References

[1] "Rhinoceros 7." Accessed: Aug. 09, 2024. [Online]. Available: https://www.rhino3d.com/7/
[2] "ZEISS Inspect Optical 3D." Accessed: Aug. 09, 2024. [Online]. Available: https://www.zeiss.com/metrology/en/software/zeiss-inspect/zeiss-inspect-optical-3d.html