WAAM SURVEY

This survey aims to explore user perceptions regarding the importance and ease or difficulty of customization in WAAM (Wire Arc Additive Manufacturing) production. The survey was conducted online between July and October of 2024 with fifty-seven participants.

People who noted experience or expertise in WAAM on their LinkedIn profile were invited to share their perspectives. Participation in this survey was voluntary and anonymous with participants informed that the results may be published in a scientific paper.

The goal was to evaluate levels of customization in the WAAM process. This includes setting parameters, adding devices, gathering data & developing adaptivity.

The survey supported a PhD focused on distributed communication for WAAM production, at the Chair for Individualized Production, RWTH Aachen University, Germany,

There were two short sections to this survey.

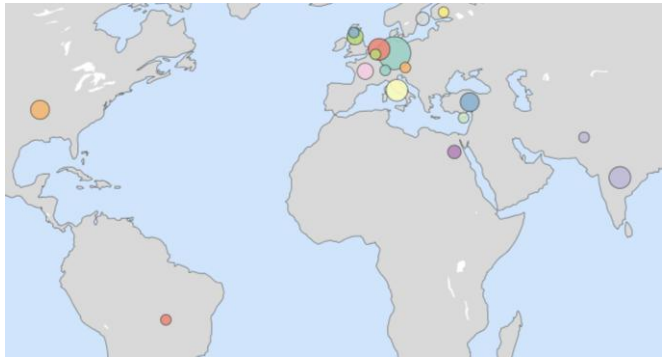
The survey should have taken between 5-10 minutes.

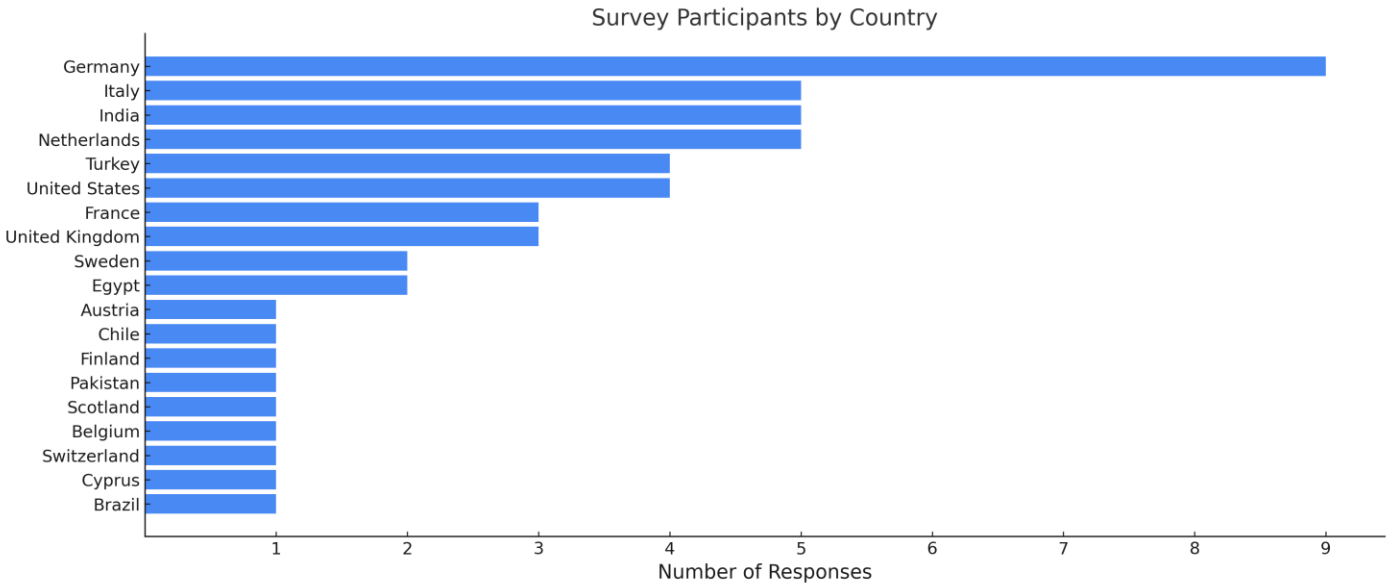
Section 1 Evaluates importance / ease of use and how WAAM is utilized in production.

Section 2 Evaluates how WAAM integrates customization.

Participants were asked to mark any option that describes your WAAM process.

Additional options could be entered in the space left for other information.



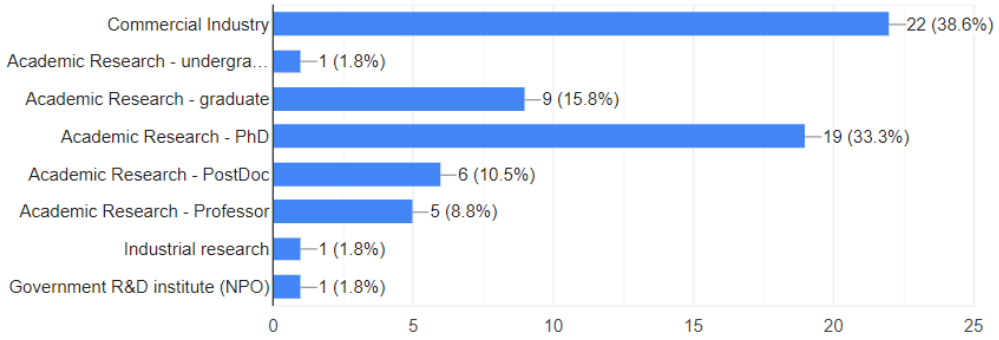


WAAM SURVEY

1. These initial questions seek to understand your perspective on WAAM.

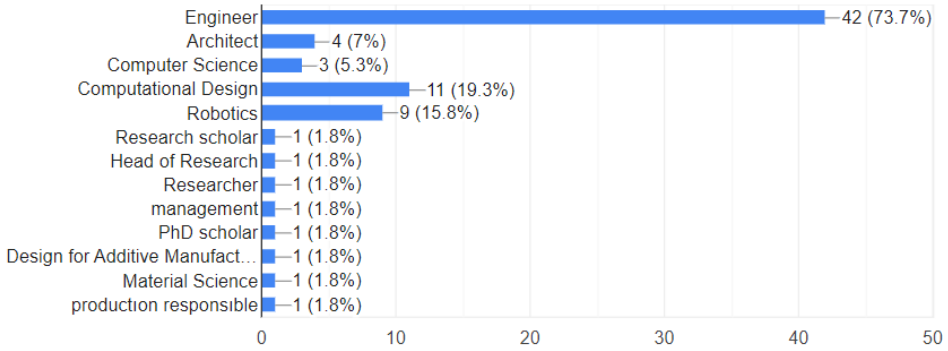
Are you working primarily in the commercial industry or in academic research?

57 responses



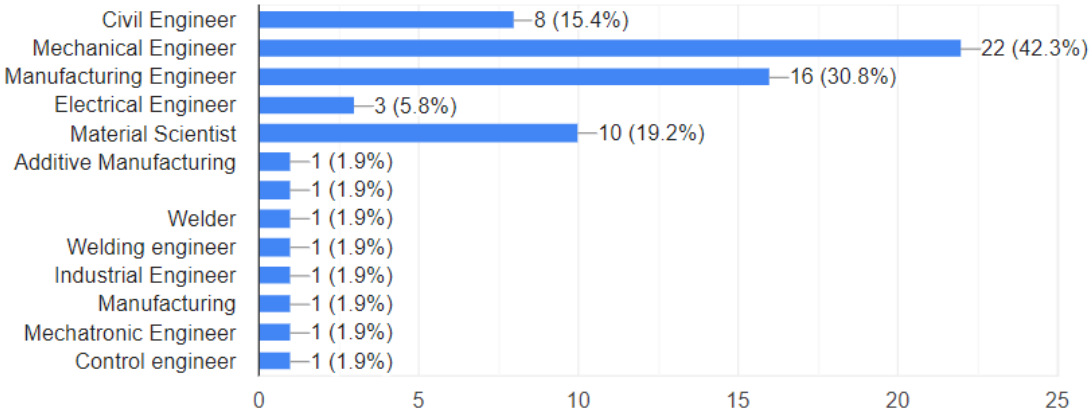
2. Which best describes your role?

57 responses



3. If you are in Engineering please describe your field.

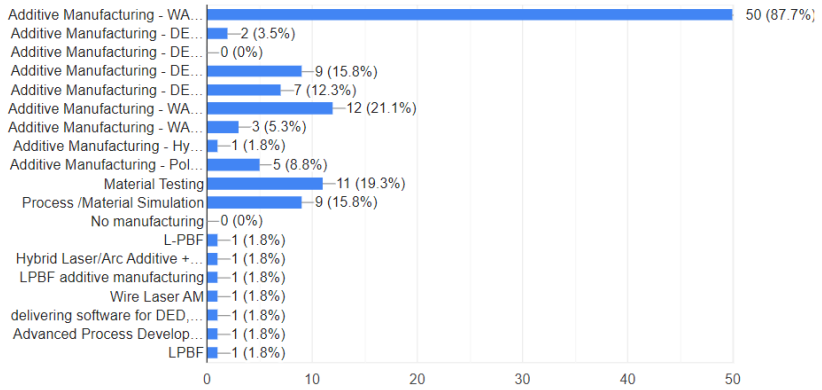
52 responses



4. Which form of additive manufacturing are you engaged in?
In the following questions, if you are working with partners to produce prints, please describe their setup

check any options that apply

57 responses



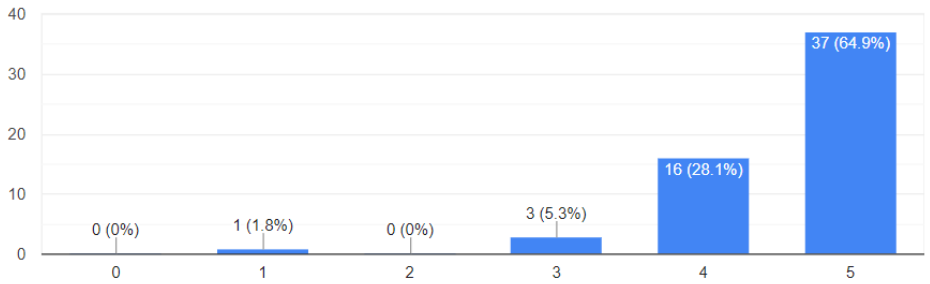
WAAM SURVEY

5. The following section aims to understand certain aspects of the WAAM process and evaluate how important they are and how easy they are to use.

On a scale of 0 to 5, with 0 being not important and 5 being very important.

How IMPORTANT is it to be able to customize robot path planning?

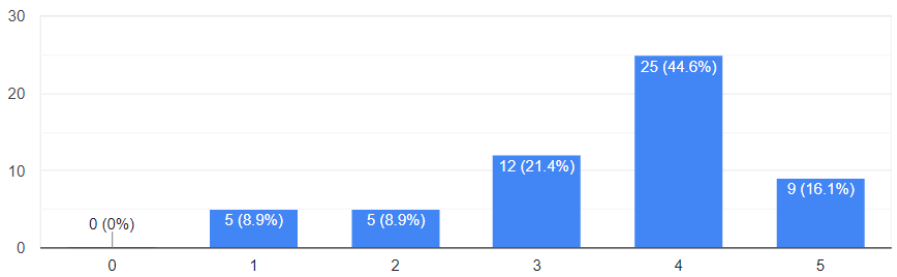
57 responses



6. On a scale of 0 to 5, with 0 being very easy and 5 being very difficult.

How EASY or DIFFICULT is it to customize robot path planning ?

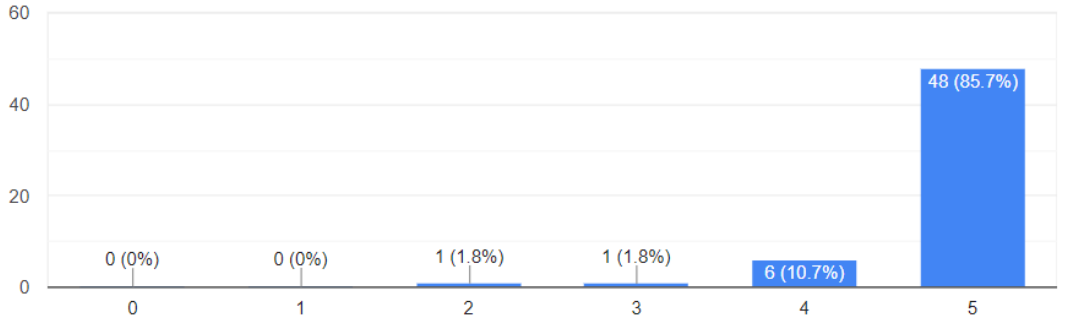
56 responses



7. On a scale of 0 to 5, with 0 being not important and 5 being very important.

How IMPORTANT is it to be able to customize welding process parameters?

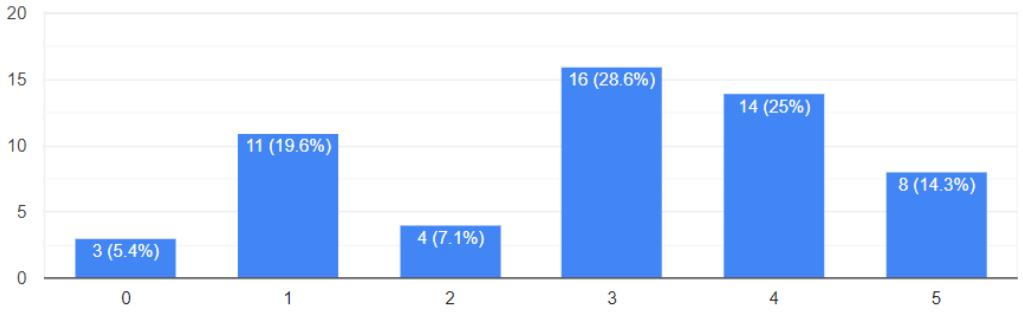
56 responses



8. On a scale of 0 to 5, with 0 being very easy and 5 being very difficult.

How EASY or DIFFICULT is it to customize welding process parameters?

56 responses

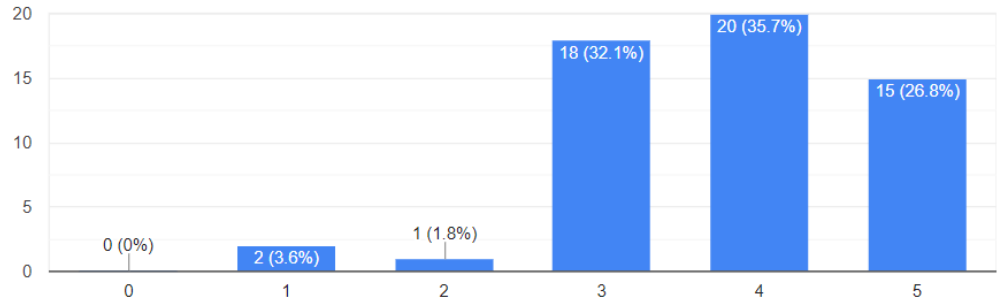


WAAM SURVEY

9. On a scale of 0 to 5, with 0 being not important and 5 being very important.

How IMPORTANT is it to be able to add or replace a device (welding power source, sensors, or auxiliary machines) to the WAAM process?

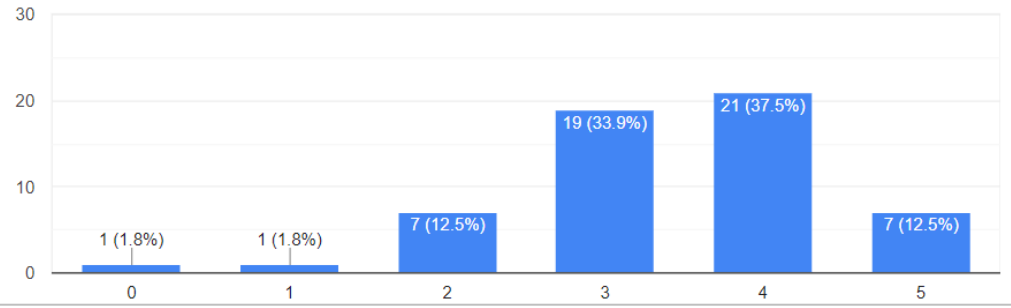
56 responses



10. On a scale of 0 to 5, with 0 being very easy and 5 being very difficult.

How EASY or DIFFICULT is it to be able to add or replace a device (welding power source, sensors, or auxiliary machines) to the WAAM process?

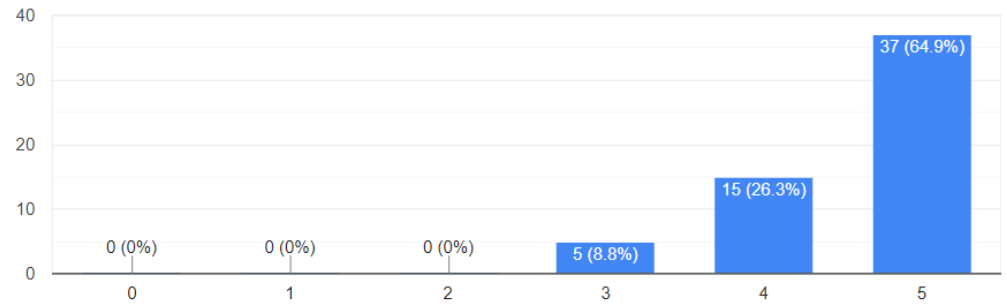
56 responses



11. On a scale of 0 to 5, with 0 being not important and 5 being very important.

How IMPORTANT is it to track/collect data from devices (robots, machines or sensors) in the WAAM process?

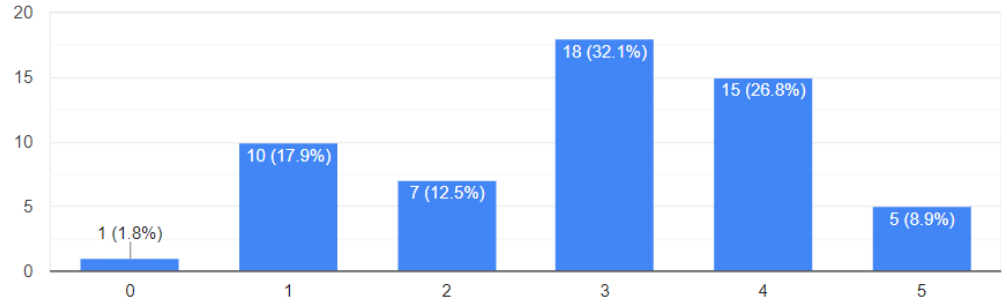
57 responses



12. On a scale of 0 to 5, with 0 being very easy and 5 being very difficult.

How EASY or DIFFICULT is it to track/collect data from devices (robots, machines or sensors) in the WAAM process?

56 responses



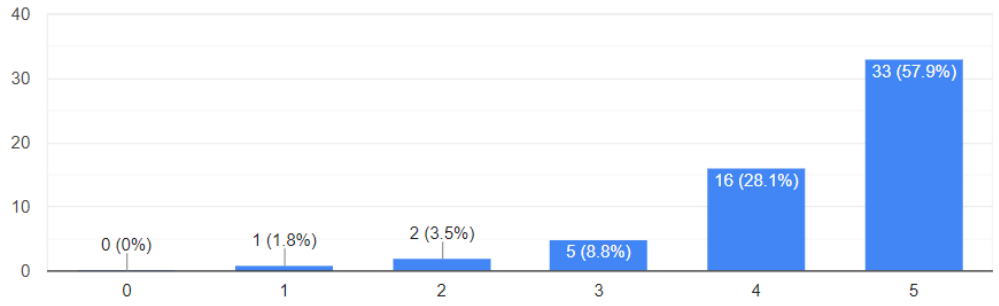
WAAM SURVEY

13. On a scale of 0 to 5, with 0 being not important and 5 being very important.

Adaptivity refers to the ability to adjust and optimize process parameters in real-time to accommodate deviations between ideal digital planning and actual production outcomes. Many adaptive strategies exist for WAAM. One example is using distance measurements to adjust torch to material distance during WAAM. Another example would be to adjust layer height based on scanning of previous depositions.

How IMPORTANT is it to have adaptive processes/programs in the WAAM production?

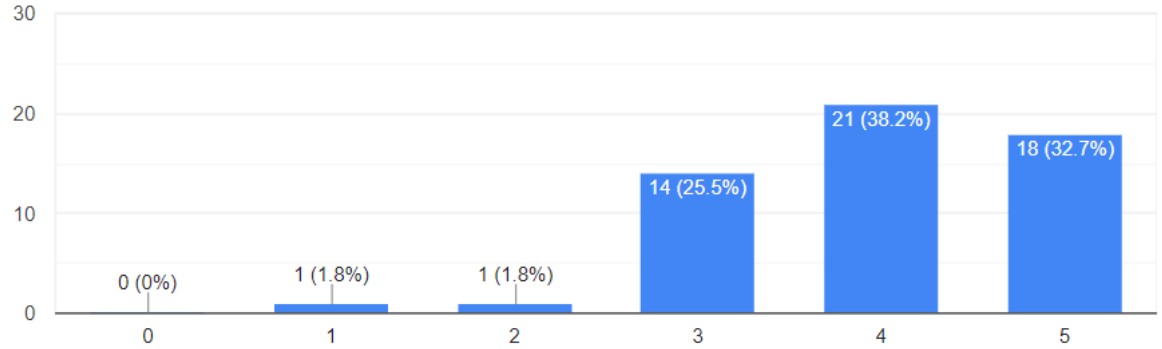
57 responses



14. On a scale of 0 to 5, with 0 being very easy and 5 being very difficult.

How EASY or DIFFICULT is it to integrate adaptive processes/programs in WAAM production?

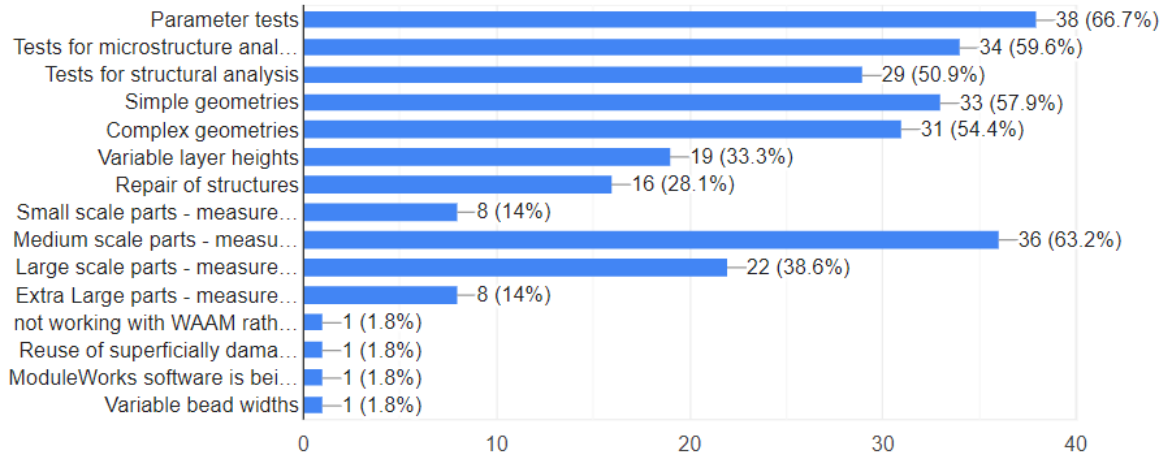
55 responses



WAAM SURVEY

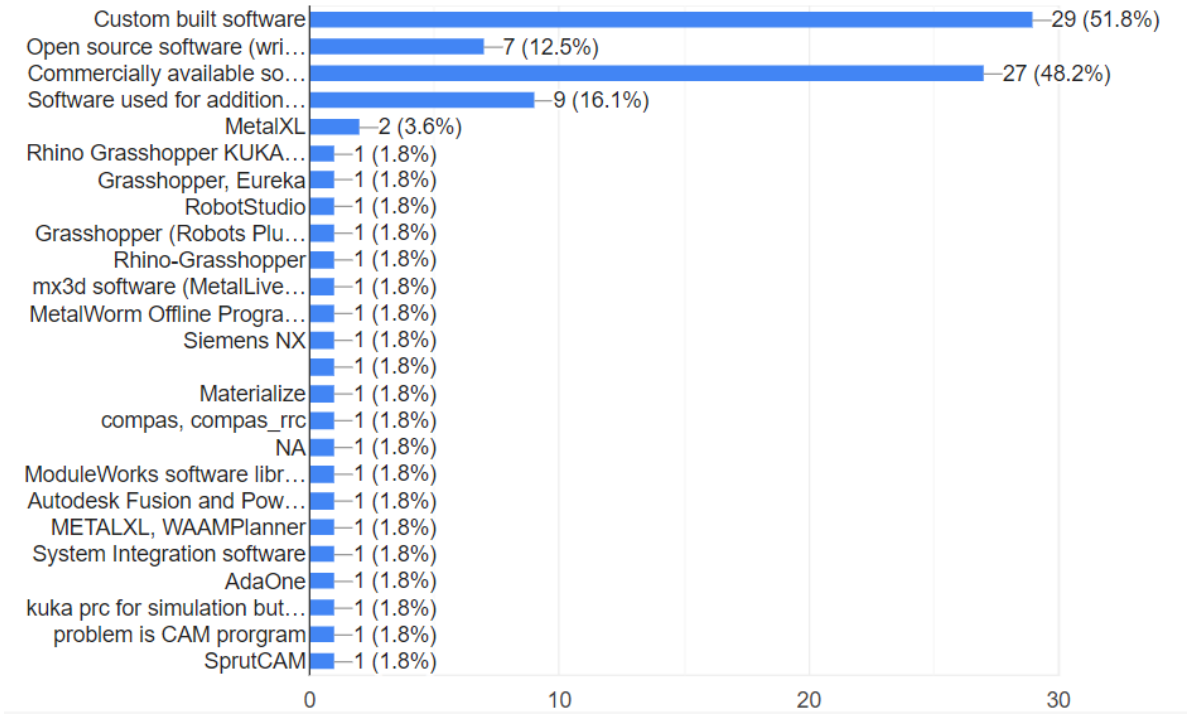
15. These next questions aim to understand the type of geometry you are printing with WAAM.
Please select which best describes your WAAM production.
check any options that apply

57 responses



16. These next questions aim to understand the software used to generate WAAM programs. Please check which best describes the software utilized for WAAM production?

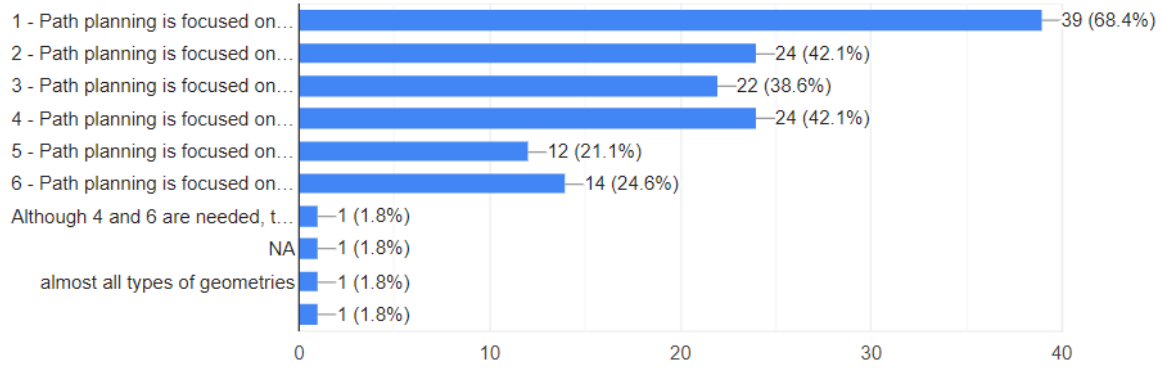
56 responses



WAAM SURVEY

17. WAAM programs generate path planning for moving the torch while depositing material. Different WAAM processes vary in their need for customized path planning. Please describe the path planning strategies you utilize in your work.
check any options that apply

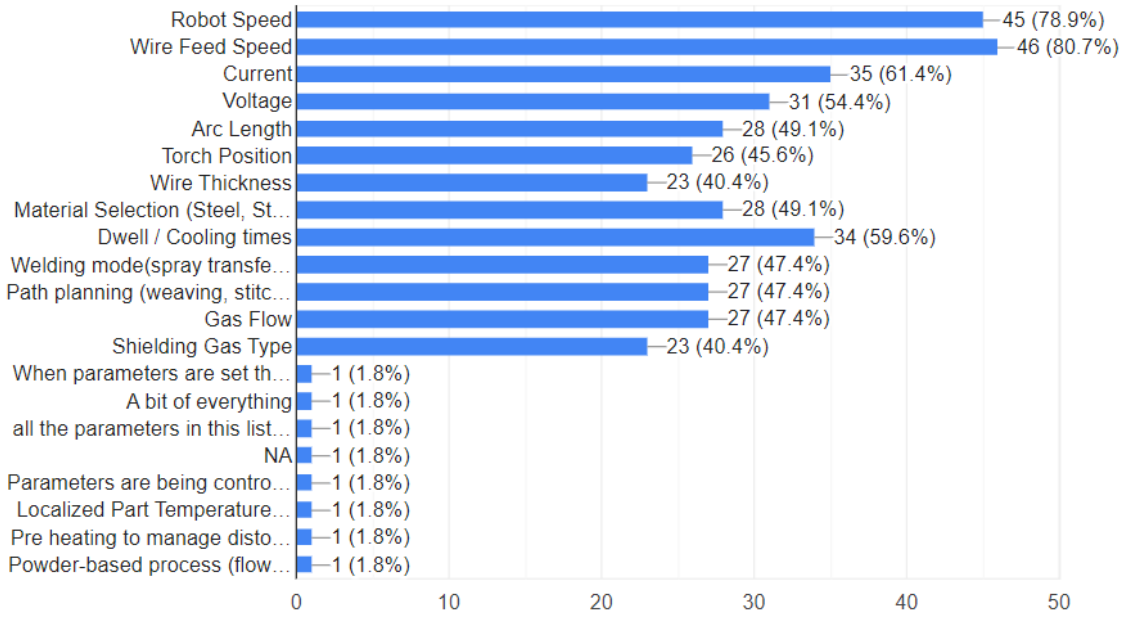
57 responses



18. WAAM production requires setting of process parameters to achieve desired results.

Please select which parameters you are adjusting to optimize the printing process.
check any options that apply

57 responses

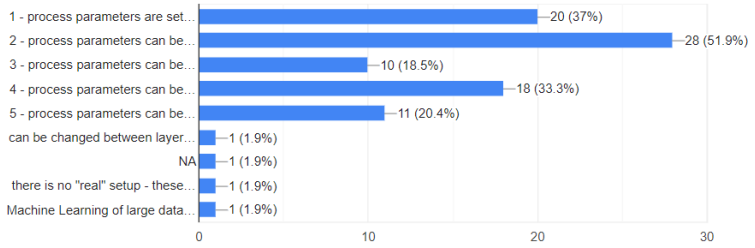


WAAM SURVEY

19. WAAM production can benefit from the customization of process parameters. Custom programs may require changing the Robot Speed , Wire Feed Speed, Current/Voltage or other process parameter settings throughout the process.

In your WAAM setup, please describe your software's ability to customize process parameters.
check any options that apply

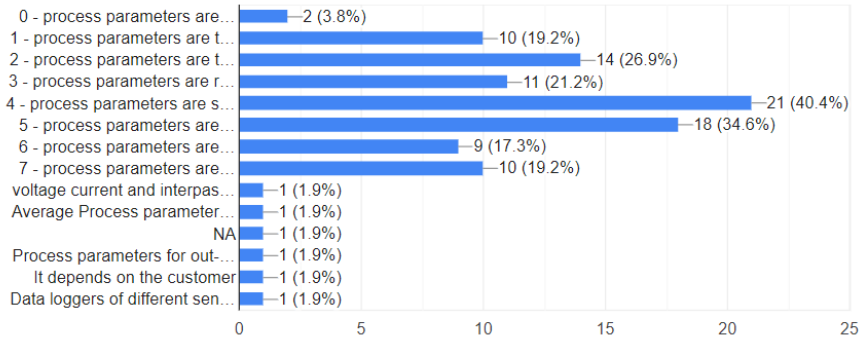
54 responses



20. Customization of process parameters are used to create different weld geometries and structural properties. During production many different process parameters may be set.

In your WAAM setup, please describe your process for tracking the changing process parameters, either in robot or welding power source.
check any options that apply

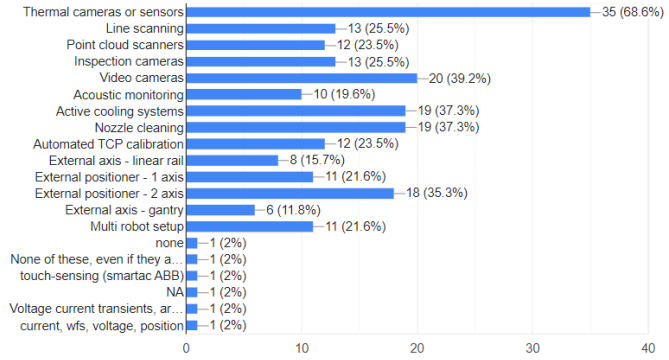
52 responses



21. WAAM production is a complex process which can benefit from integration of additional devices such as sensors to monitor the process or auxiliary machines to improve the production.

In your WAAM setup, please describe which sensors or auxiliary machines benefit your process
check any options that apply

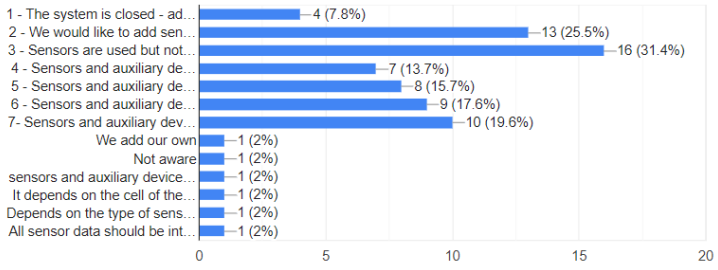
51 responses



22. WAAM production can benefit from integration of additional devices such as sensors to monitor the process (thermal, scanners, acoustic) or auxiliary machines to improve the production (cooling systems, nozzle cleaning systems, etc...)

In your WAAM setup, please describe your cells process for integrating additional sensors or auxiliary machines.
check any options that apply

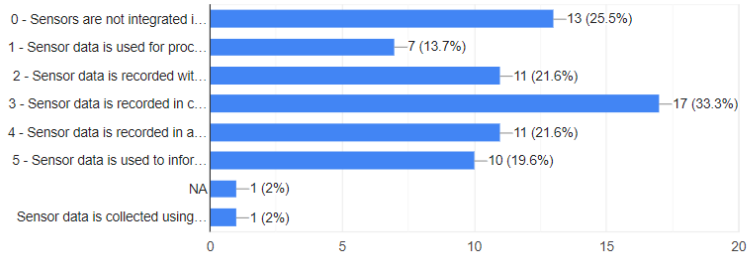
51 responses



23. Sensors provide information that can be used for process monitoring, quality control and defect detection. This requires access to data and correlation with robot movement.

In your WAAM setup, please describe your software's integration of sensor data.
check any options that apply

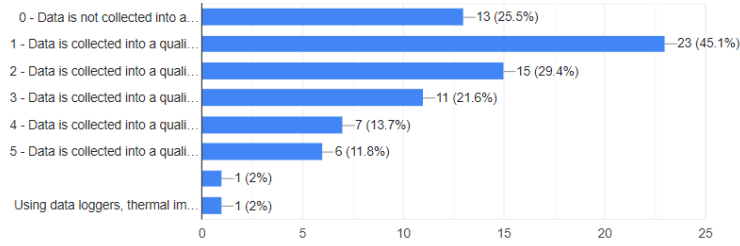
51 responses



24. The collection of process parameters and sensor data can be used to create quality control reports that help to detect defects, optimize processes, or certify parts.

In your WAAM setup, please describe how the process parameters, sensor data and any additional information is collected.
check any options that apply

51 responses

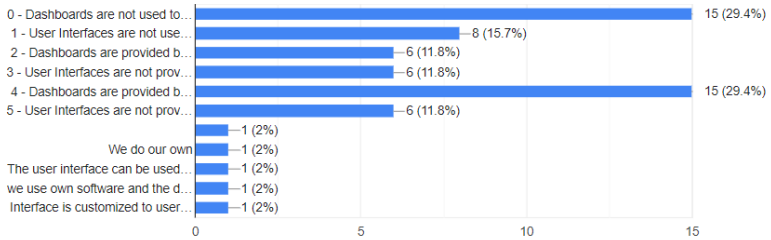


WAAM SURVEY

25. Dashboards enable the operator to visualize process information. User Interfaces enable the operator to interact with the WAAM production throughout the print (for instance pausing, canceling, resetting, adjusting speed or welding pawer source parameters)

In your WAAM setup, please describe the use of dashboards and user interfaces.
check any options that apply

51 responses



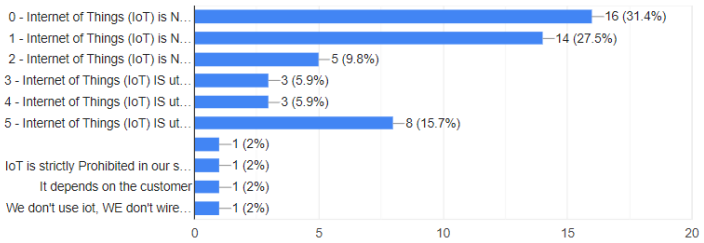
27. The typical method for connecting devices to a robot cell is to hard wire them through the control box communication systems of the robot.

Internet of Things (IoT) enabled processes allow for distributed communication between devices.

This can be used for connecting devices in cyber physical systems. For example, the welder may receive process commands over a cloud based system rather than through a hard wired system. This can be used to integrate auxiliary machines such as IoT enabled cooling systems, sensors, middleware software as adaptive services, or for predictive maintenance.

In your WAAM setup, please describe the level of Internet of Things (IoT) enabled infrastructure.
check any options that apply

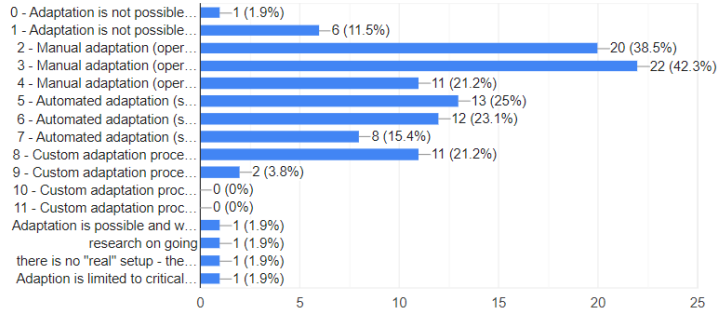
51 responses



26. WAAM production is a dynamic process where the estimated digital model is often different from the actual printed outcome. Adaptation can be used to fix errors in printing and overcome the deviation between digital and physical. Adaptations can range from changes to process parameters between sections, between layers or even adaptation of the process while printing.

In your WAAM setup, please describe the possibility for adaptive processes.
check any options that apply

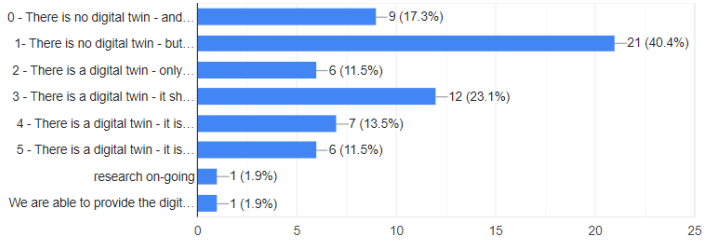
52 responses



28. Digital twins or shadows allow for the operator to visualize the process in the digital environment.

In your WAAM setup, please describe your the level of digital twin or shadow that is available to the operator.
check any options that apply

52 responses



WAAM SURVEY

29. What is the biggest challenge you face in WAAM production?

43 responses

Setting process parameters to achieve quality welds

Real element is different from the model

Large scale structures

Extremely high temperature process, Inter layer cooling time is high even when energy density (low wire feed speed, high travel speed) is less.

heavy material

Hardware-Software Integration, Legacy robotics systems are not enough for customization, A company should go full ROS(robotic operating system) or make a system with step motors to have enough independence.

accurately monitoring the process to correlate failures in the material to the printing process.

the great challenge of waam is to be able to print anything without the deposition of the layers influencing

Thermal management to ensure accuracy

we don't have a cold metal transfer system our principal trouble is overheating in a continuous weld, and warping of printing what leave to coincide with the top layers of the toolpath

choosing adaptive process parameters

Our work is mainly research based on the material. Our interest lies on process parameters - alloy - properties relationship

Maintaining constant Temperature gradient

Make a lot of trials and errors to get successful parameter for any given part. Needed to implement AI & ML to predict parameters nearly for a part build up. Need to have training data sets

Lack of reproducible success and difficulty to work with experimental setup.. Also metallography is so slow and resource-intensive

process parameters

Finding the right process parameters for hard facing materials, controlling the heat input and avoid cracking when using hard materials

Arc control

Slicing solution

gravity

Standards for quality control

not sure

Reproduction of the same part with same aspects

Variations of process parameters is required depending on the geometry

Not in production but in DfAM - it is still challenging to design a WAAM part from scratch. In production, the lack of a full understanding of the deposited seam. More sensor data would be useful to fully recreate what has been printed in previous layers.

I am not involved in the manufacturing process

Getting it first time right (issues with finding right parameters and timing to cope with thermal issues and shape deviations).

Arc failures

limited business cases

Improved deposition rate

Lack of resources to pursue all of our ideas.

Mainly property related, Issues related to different level of heat accumulation and cooling rates in bulk printing. Additionally this might cause height differences between layers.

Customers not understanding what they want

Precision

Standardisation of process and certification of parts

Good quality build (Accurate and dense parts).

Automating slicing orientation in complex geometries.

Difficulty in controlling the dimensional accuracy

increasing the deposition rate

Reduction of costs

Avoid defects and repeatability.

Geometrical accuracy of parts

Thermal distribution control

WAAM SURVEY

30. What innovation or developments would you like to see in order to improve WAAM production and accelerate its ability to positively impact industry.

36 responses

Readily available slicing software

Incorporation of AI & ML to easily and accurately predict process parameters, path strategies,

More publicly available data and standards

Make the system work closed loop where it automatically changes it's parameters based on the feedback recieved from the sensors, High deposition rate, Simulation of WAAM to reduce time consumed in DOE to find right parameters.

Less heat input, finer deposits, large scale parts

Parameter optimization in Situ

cutting from plate

Close-loop control based on online monitoring

Colder processes

Higher deposition, controlled thermal management

Welding Systems and their respective hardware components made specifically for WAAM

Multi-material WAAM, Cybersecured work flow, Robotic WAAM systems, Online quality control, Data analytics

more Open welding machines

MI and AI approch to control input parameters

WAAM process parameter matrix, plug and play sensors, smaller end effectors, mobile welding robots

Reliable and fast process simulation (macro and meso scale).

Customization in software, automated nozzle change, real time temperature camera, adaptive and automated 3D scanning of parts

widely recognised certification procedures to lead to industry acceptance

The possibility of deploying varying process parameters and adaptive path planning through online feedback

Shorten production lead times to deliver faster

Acceptance of COSMO(TM) as a design tool

cooling systems for the continuous prints, and the integration of sensors more affordable

costumized energy input regarding the boundry conditions

Alloy development for AM through WAAM; integrated error detection and correction; integrated CNC, PWHT and WAAM system

Online NDT

The process needs to be more robust and simpler, allowing repeatability and easy of use.

Incorporate sensors and IoT to effectively gather information regarding temperature and the other process parameters needed for optimization

More data tracking and adaptivity

in site contruction

A closed loop feedback system which can make the robot self-learning can improve the process' production rates as well as quality.

integration within the architectural field

Communication systems between any kind of robot and any kind of welding machine. Both hardware and software support.

perhaps simpler than designing the product to be printed, but in reality I haven't yet found what the turning point could be

Accurate temperature measurements to monitor the cooling rates.

Simplification. It has become far to complicated