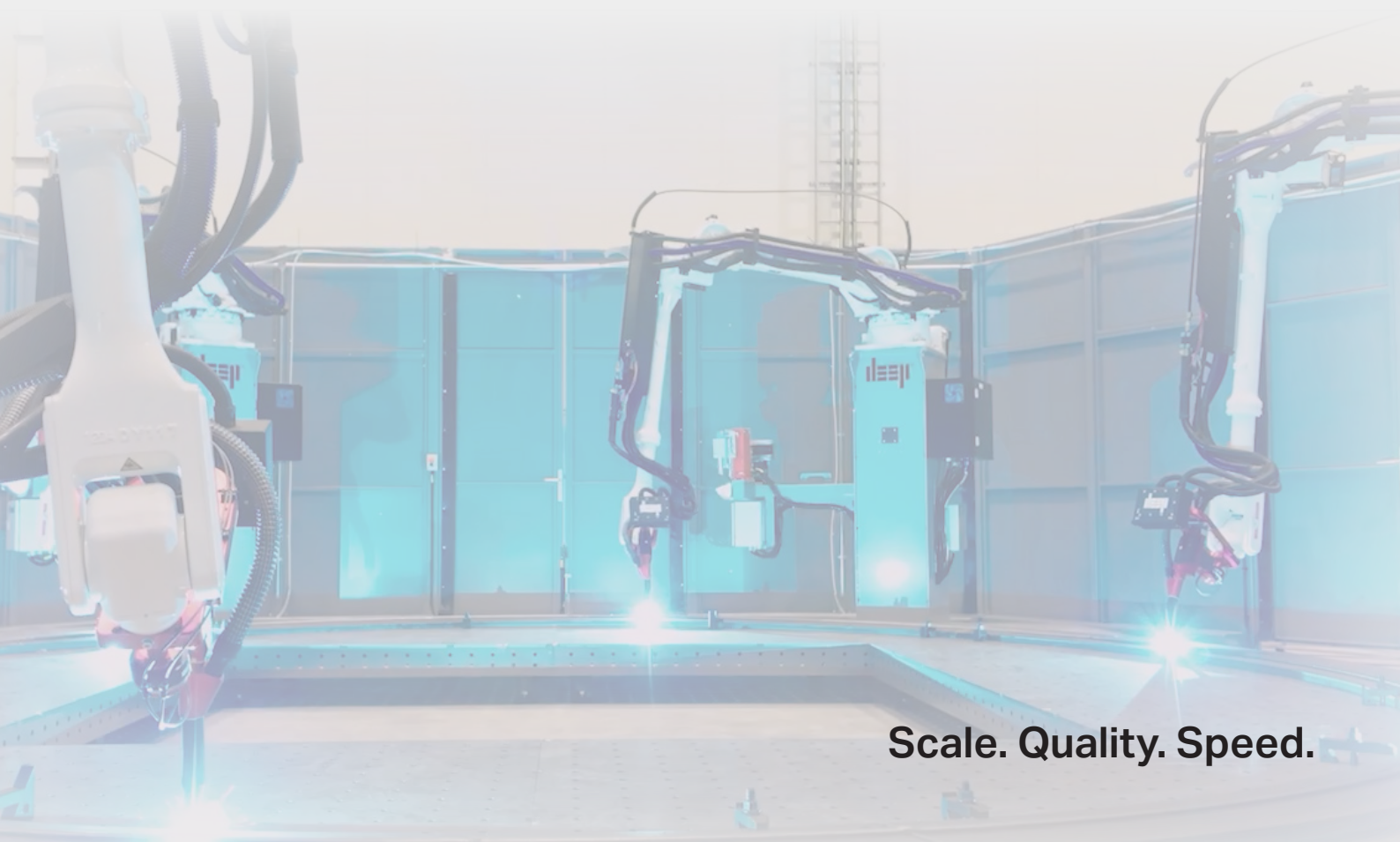


# Scaling WAAM: How Synchronised Multi-Robot Deposition Tackles Large Format Metal Additive

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**Scale. Quality. Speed.**

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## Underwater habitats

DEEP's mission is to make humans aquatic by establishing a permanent presence beneath the ocean. Achieving this requires improving access to the oceans and enabling deep sea research at scale. This challenge defined DEEP's early focus on underwater habitats, a field that has seen little progress since the 1970s, and set the direction for the developments that followed.

## The challenge of traditional manufacturing

To meet the ambitious timelines and complex design requirements for the world's first classed underwater habitat, DEEP first looked to traditional manufacturing. This was primarily a combination of forgings, castings, rolled plate and weldments.

With a long backlog of high value repeating orders that the underwater habitat programme was unable to compete with, DEEP looked to alternative manufacturing methods.

Coming out of the COVID-19 pandemic, a wave of foundry, mill and plant shutdowns had meant that lead times were getting longer and longer. Especially with large components and thick plate suppliers, there were only a handful of suppliers in the region that could manufacture the size, quality, and complexity that DEEP desired.

*One of the original designs for DEEP's underwater habitats.*



## Benefits of Wire Arc Additive Manufacturing (WAAM)

And the emergence of DEEP Manufacturing

As an underwater technology company, DEEP aimed to be at the forefront of technology and development. Scoping into the world of advanced manufacturing, there was a candidate technology that offered quicker production times, enabled further design complexity and flexibility, and required significantly less capital investment compared with setting up a traditional manufacturing facility – Wire Arc Additive Manufacturing (WAAM). At this point, **DEEP Manufacturing** was born.

WAAM is based on traditional MIG/MAG welding and was first patented in the 1920s, with renewed interest in the 1990s driven by advancements in computer-aided design and manufacturing (CAD/CAM), improved welding techniques and waveform technology, and developments in robotics.



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### Compared with other metal additive technologies, WAAM has several clear advantages:

Higher deposition rates, reducing the time required to manufacture parts.

Wire-based feedstock, which is lower cost, more readily available, and presents fewer safety concerns than powder.

Established welding knowledge, standards and industry experience.

Larger achievable build volumes.

### When compared with traditional manufacturing, WAAM has the following advantages:

Design flexibility, without the need for large, long lead-time tooling such as casting moulds.

Improved material homogeneity, particularly when compared with thick rolled plates in excess of 100mm (as noted in ASTM A20).

Reduced lead times and inventory requirements, with repeat or similar components produced in months rather than years.

Lower environmental impact, with reduced material waste, energy consumption and associated emissions.



## Evolution to multi-robot WAAM

While WAAM offered clear advantages, the limitations of single-robot systems became evident at the scale required.

For DEEP's flagship Sentinel project, individual segments exceeding 6m in diameter and 3m in height would have required more than 18 months of continuous 24/7 production using a single system. At this duration, production timelines became commercially impractical. In parallel, the working envelope of standard robotic systems fell significantly short of the required build volume.

Alternative approaches, such as large custom gantry systems, were considered, but introduced substantial capital expenditure, with costs potentially reaching tens of millions.

To meet both scale and delivery requirements, the focus shifted towards multi-robot WAAM. By deploying multiple synchronised systems, it became possible to increase deposition rates while extending the effective work envelope. This led to the development of the Hexbot system, capable of producing components up to 6.2m in diameter and 3.2m in height.

## Development of multi-robot WAAM

The development of the multi-robot capability was carried out in 15 months through a collaboration between DEEP Manufacturing and RAMLAB. The focus was on creating a scalable software and system architecture that addressed key safety, control, accuracy and operational requirements.

### Safety and system integrity

To ensure safe operation across multiple robots working in parallel:

#### Safety stops

Emergency stops and signals are linked with all individual robots.

#### Interlocked operation

Individual robots cannot enter automatic mode unless all system-wide safety interlocks are secured.

**Synchronisation and process control**

To enable coordinated operation across multiple systems:

**Multi-robot synchronisation**

Robots operate in lockstep, maintaining alignment across job, layer, stage and process.

**Multi-robot orchestration**

Systems coordinate across workflows including temperature scanning, geometry scanning, compilation, torch cleaning and welding.

**Multi-robot job control**

Jobs can be uploaded, modified, monitored and reported through a centralised control approach.

**Multi-robot program framework**

A flexible programming structure supports variation in robot count, layers, weld passes, weld lengths and operations.

**Accuracy and calibration**

To maintain geometric consistency across large-scale builds:

**Multi-robot origin calibration**

All robots reference a shared coordinate system.

**Multi-robot overlap calibration and correction**

Welding poses are adjusted in overlap regions to ensure smooth and continuous material deposition.

**Collision avoidance and operational resilience**

To maintain stability during long-duration builds:

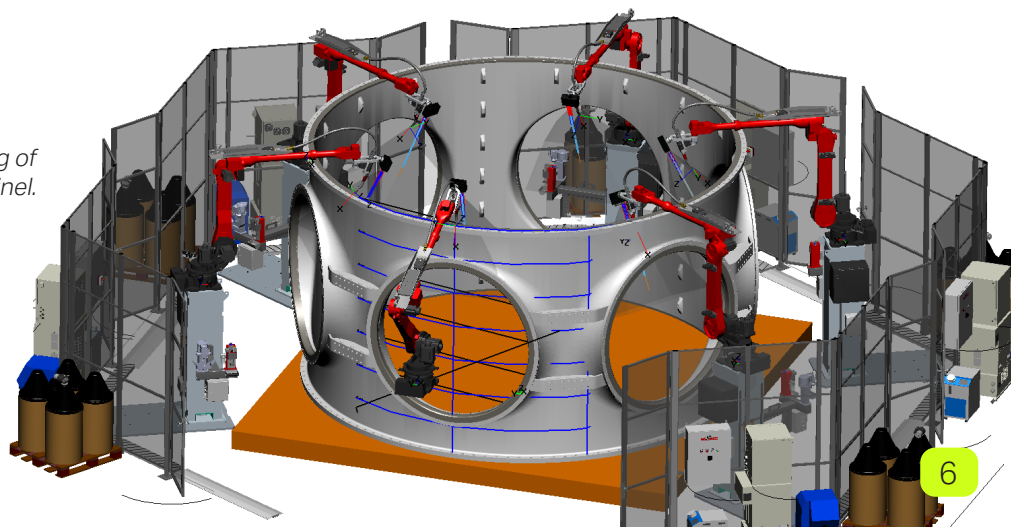
**Multi-robot collision avoidance**

Robots are aware of their current pose and travel vector to ensure no accidental crashes.

**Multi-robot error recovery**

Workflows are designed to ensure that recovery is possible if errors occur mid-job while system stays synchronised.

*Digital mockup of the printing of DEEP's flagship habitat, the Sentinel.*



## Performance validation of multi-robot WAAM

With any robotic system, absolute accuracy can be affected by calibration, static, dynamic and wear-related errors. In WAAM, this directly influences whether the manufactured component meets its intended geometry. Although WAAM produces near-net-shape parts, machining is still required, and improved accuracy reduces the amount of overbuild. This is particularly important for mass-critical applications and where minimising machining time and material removal is a priority.

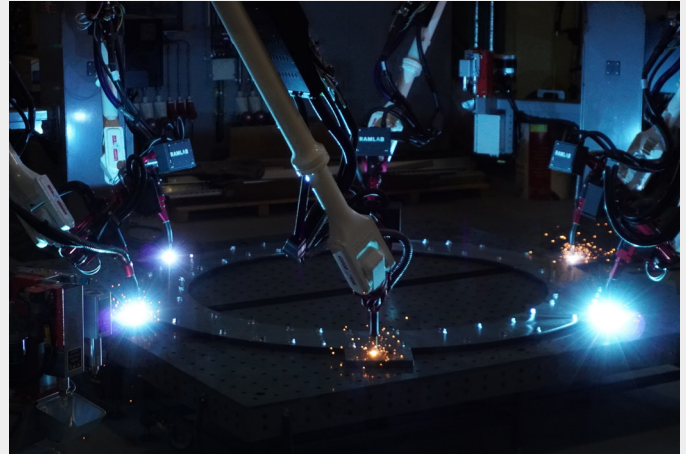
Accuracy becomes even more critical in multi-robot systems operating at large scale. Increased production rates and expanded build volumes only deliver value if the final component meets defined dimensional and geometric requirements.

The performance of the Hexbot system was therefore evaluated across local accuracy, defined by the smoothness of transition regions between robots, and global accuracy, defined by the dimensional trueness of the final component.



Close-up of overlap region from multi-robot WAAM system.

By applying calibration and correction strategies within overlap regions, local accuracies comparable to a single robot system were achieved, with no distinguishable transition between robot contributions. This is a key requirement for industrial deployment, as it ensures



Six robot system trial.

that increased deposition rates and larger build volumes do not introduce additional machining burden or compromise component integrity.

For global accuracy, DEEP Manufacturing's proprietary origin calibration methodology was applied across components ranging from 4m to 6m in diameter. Circularity and dimensional tolerances were achieved well within the 0.5% requirement specified by DNV for cylindrical structures. This provides clear validation that multi-robot WAAM can meet the geometric standards expected for safety-critical, classed components.

These results demonstrate that the calibration and correction framework developed for multi-robot systems is capable of maintaining geometric accuracy at scale. This enables the benefits of increased production rate and expanded work envelope to be realised without introducing additional risk in downstream machining, inspection or certification.



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## Multi-robot challenges and further development

The application of synchronised multi-robot WAAM at large scale introduces a distinct set of engineering challenges. Components that take advantage of increased build volume and production rates are typically large, requiring significant volumes of deposited material and repeated heating and cooling cycles throughout the build.

This introduces challenges relating to thermal distortion of both the component and the substrate, which are further compounded by the number of heat sources involved, the size of the component, and the potential for interruptions during long-duration builds.

To address this, DEEP Manufacturing is

currently exploring thermal modelling and testing methods to better predict, reduce and account for these effects. One such approach is geometry compensation, where the designed toolpath is adjusted to account for expected distortion, allowing the final component to settle into the intended geometry.

While the framework and methodology for multi-robot toolpath design are established, a user-friendly and efficient tool for doing so remains in development. DEEP Manufacturing is therefore continuing this work in collaboration with partners, with a focus on improving usability and supporting wider industrial application.

## Multi-robot opportunities

Aside from the use case that DEEP Manufacturing has identified for multi-robot WAAM in the form of increased production rates and increased build volumes, there are also other opportunities for value and innovation.

Multiple processes can be used simultaneously to either increase efficiencies or improve insight – for example a trailing robot that could perform visual inspection, 3D scanning, stress relieving or even ultrasonic testing.

As a subset of this, multiple materials may be used in the same job simultaneously, allowing multiple materials to be embedded

within a component. Alternatively, other additive technology such as laser or plasma may also be used if there are different requirements for different areas of the component.



*The original Hexbot system.*

## Future work and next steps

DEEP Manufacturing continues to develop and refine multi-robot WAAM capabilities, with a focus on industrialisation, scalability and repeatability across a range of component types and use cases. Ongoing work includes the assessment of alternative system configurations, further development of toolpath generation methods, and continued validation of process performance at scale.

These efforts are aimed at ensuring that multi-robot WAAM can be reliably applied to real-world components, supporting consistent delivery of large-scale, high-integrity structures across different industries and environments.

In parallel, DEEP Manufacturing is engaging with commercial partners to apply these developments within the context of specific components and projects. This includes both established use cases and the exploration of new applications where multi-robot configurations can provide a practical solution to manufacturing challenges.

## Conclusion

The development of synchronised multi-robot WAAM represents a practical step forward in delivering large-scale, high-integrity components at the pace modern programmes demand. By combining increased deposition rates, expanded build volumes and controlled accuracy, this approach enables faster delivery of safety-critical structures, while reducing reliance on constrained traditional supply chains.

While challenges such as thermal management and toolpath generation remain active areas of development, the progress to date shows that multi-robot systems can operate as a reliable and scalable manufacturing solution. As these capabilities continue to mature, they will play a central role in enabling larger, more complex components to be manufactured with greater certainty.



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