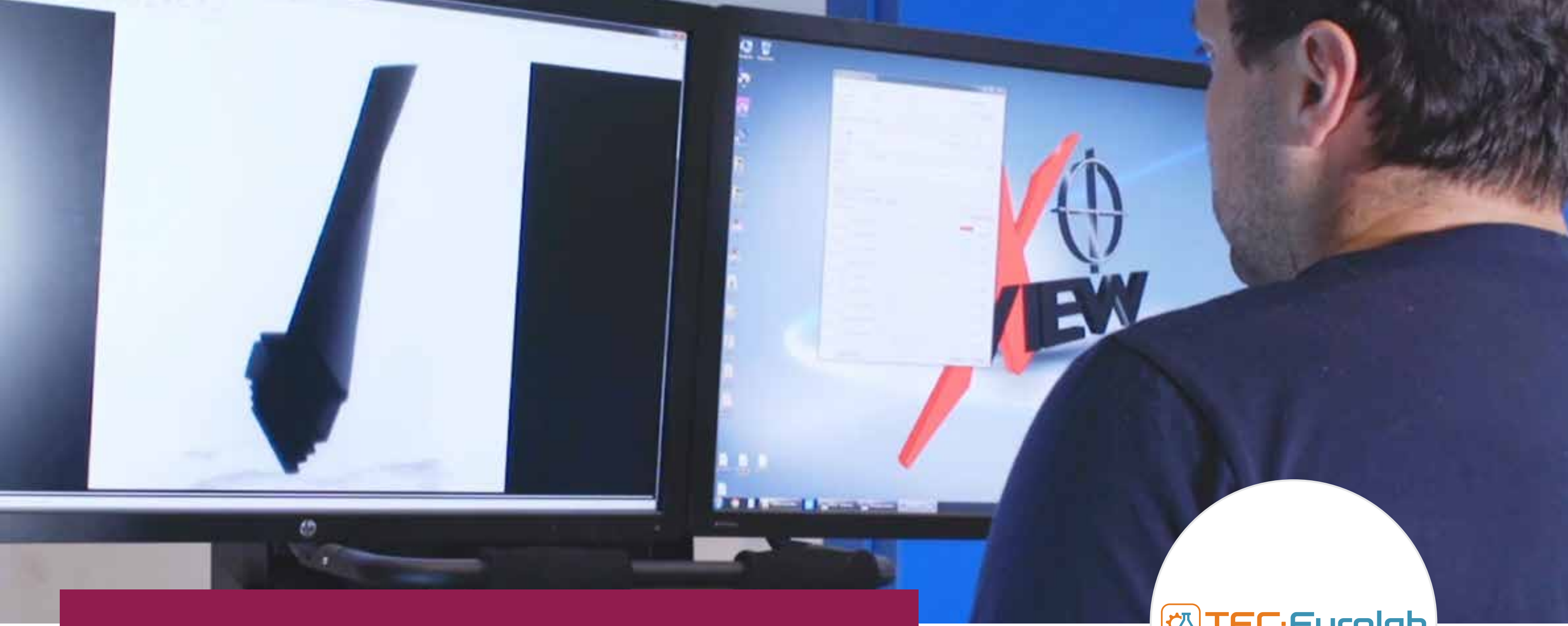

Enhancing quality assurance in additive manufacturing: harnessing the power of industrial computed tomography

Revolutionizing non-destructive testing for AM components through comprehensive defect and dimensional analysis

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In recent years, additive manufacturing (AM) has revolutionized the field of manufacturing, enabling the production of components with high geometric complexity and functional sophistication. Like for subtractive manufacturing, ensuring the quality and structural integrity of these components is critical to their safe and effective use. The use of non-destructive testing (NDT) methods is crucial to verify the quality of AM parts, prior to their intended functional use, at all stages of the production process – from material feeding to optimization during production and from verification of surface properties to inspection during use.

In order to comprehensively evaluate the best approach for non-destructive testing of components in AM, certain peculiarities and limitations that currently characterize all components manufactured with these technologies need to be taken into consideration. Specifically:

- Components have fundamentally anisotropic mechanical properties, which makes characterization more complex from the perspectives of material and component control;
- Online monitoring methods are being developed to detect potential defects during component production, however they need to be validated using reliable and repeatable NDT techniques;
- There is still limited literature on the impact that defects, when present in an additively manufactured component, can have on the degradation of the component's functional performance;
- For each type of manufactured component, experimental campaigns are required to correlate microstructural properties with results from NDT; establish reference benchmarks; and determine the best inspection techniques to detect potential critical defects. Appropriate inputs related to component geometry, stress conditions, and material properties are required to determine the critical defect size;
- It turns out that the possible defects observed often appear to be non-repeatably distributed among different components of a series, making it more challenging to study the factors that led to the occurrence of the defect.

As is obvious, the non-destructive inspection of AM components has several critical issues and limitations. In parallel with the development of AM technologies, there has been significant progress in recent years in the field of industrial computed tomography, both in terms of its technological capabilities and its widespread acceptance.

Among all currently available NDT methods, this non-destructive diagnostic technique represents the best compromise in terms of ease of use, amount of information generated, and interpretability of results.

Computerized tomography (CT) in industry: a brief overview

Computerized industrial tomography (CT) is an advanced method of non-destructive testing (NDT) widely used in industry to inspect the internal structure of objects without causing any damage.

Similar to medical CT scans, industrial CT uses X-rays to create detailed 3D images of the inside of the object including all defects and the internal and external geometry with micrometric precision and definition.

The dimensionally calibrated 3D volume generated allows quantitative measurements to be taken.

How it works

Industrial CT works by rotating the object to be inspected while it is being scanned by an X-ray beam. X-rays pass through the object and are detected on the other side by a specialized sensor called a detector.

The detector records the intensity of the X-rays, which are influenced by the density and thickness of the material. A computer processes this data and reconstructs cross-sectional images, or "slices" of the internal structure of the object. These slices are then combined to generate a 3D image, which enables a thorough study of the object's interior.

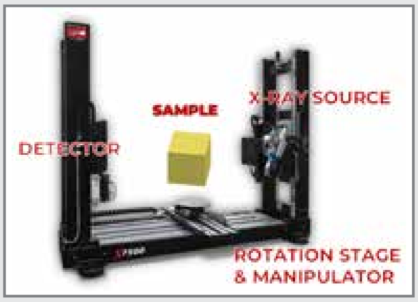


Fig. 1. Main elements of a tomographic system.

In Fig. 1, an x-ray tube acts as the source of the radiation that penetrates the object to be inspected; a high-resolution sensor, such as a flat-panel or linear detector, captures the x-rays passing through the object; the object is mounted on a rotating platform that manipulates the object and enables it to be scanned from multiple angles; a system of Cartesian axes is used to translate the x-ray images into the X, Y and Z directions; finally, software-based advanced computer algorithms process the raw data and reconstruct the 3D images into a complete volume of the inner and outer features.

The steady increase in the size of additive manufacturing systems and the adoption of higher-density metal alloys, such as copper and superalloys, have required a progressive strengthening of the power of the radiation sources used in tomographic systems in order to guarantee the quality of the reconstructed volume, detect any internal defects, and perform dimensional measurements.

In general, low voltage systems (240kV-450kV) are best suited to the analysis of low to medium density alloys and composite materials. For large, high-density alloy components, industrial tomography using a linear accelerator source (LINAC) is best for high-quality volumetric reconstruction (see Fig. 2).

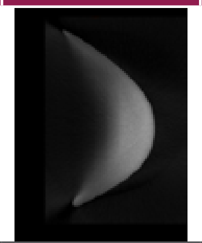
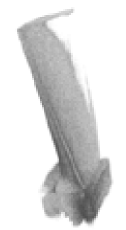
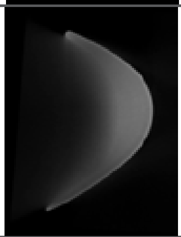
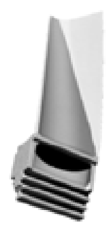
CT system	Technical data	CT 2D slice	Reconstructed CT volume
NSI X5000 	Source: 240kV–350W power output Max. resolution: 5μm		
NSI X7500 	Source: 450kV–1,500W power output Max. resolution: 70μm		
D7 6MeV LINAC 	Source: 6MeV Max. resolution: 140μm		

Fig. 2. Example of tomographic scans performed on the same nickel-based superalloy component (turbine blade), analysed on each of TEC Eurolab's three tomographic systems.

Industrial computed tomography (iCT) provides a detailed three-dimensional view of the inside of manufactured components, revealing defects, porosity and imperfections that could compromise their functionality. This article will explore the applications and advantages of this diagnostic technique for inspecting components produced via additive manufacturing and will highlight its crucial role in ensuring the quality and safety of products manufactured this way.

iCT has become an important tool in the world of additive manufacturing, enabling comprehensive defect and dimensional analysis. CT scanning allows manufacturers to assess the integrity of printed parts without compromising their structure, which has revolutionized quality control processes and led to improved productivity and reliability across the AM industry. This is because iCT is the only NDT technique that allows complete inspection of an AM component, from defect to dimensional analysis.

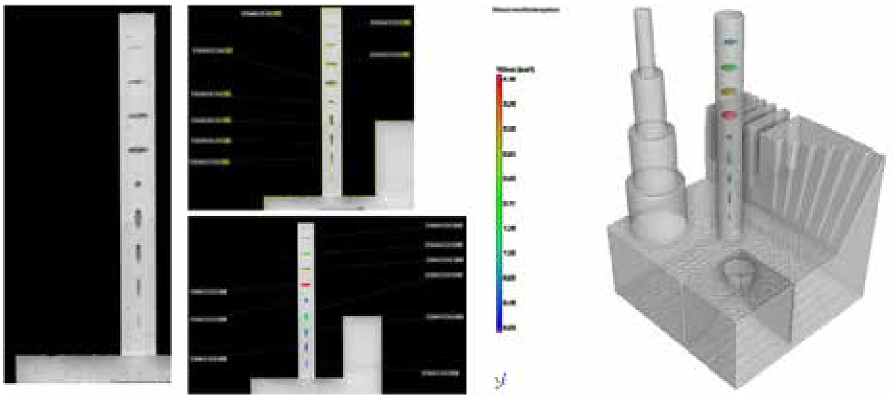


Fig. 1. Demonstrative component for defect analysis by computed tomography - example of a demonstration instrument made of AlSi10Mg alloy and containing artificially created defects to demonstrate the ability to classify and dimensionally measure any defects present in an additive component.

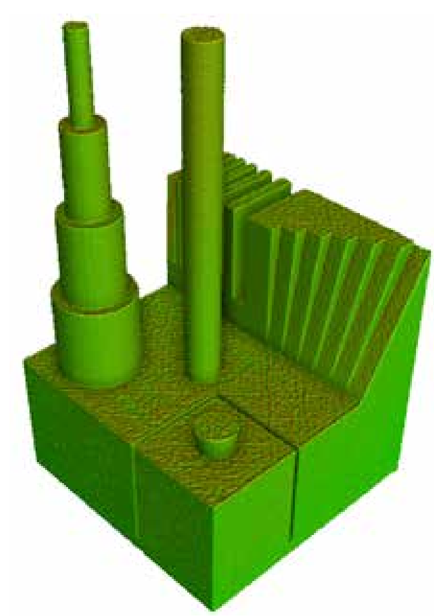


Fig. 3. Demonstrative component for defect analysis using computerized tomography - example of dimensional measurement of features in the same instrument as Fig. 1.

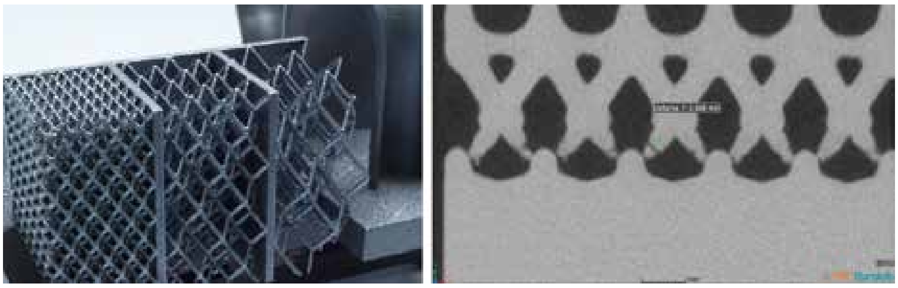


Fig. 2. Example of different types of lattice cells that can be manufactured using AM technologies (left) and a tomographic section of a lattice structure (right). Note the presence of cracks in the material at the junctions between bulk material and lattice cell sections.

Defect analysis

Various defects can occur during the AM printing process including porosity, voids, cracks, and delamination. These defects can significantly affect the mechanical strength and overall performance of printed parts. CT scanning allows engineers to detect and characterize these defects non-destructively.

CT imaging provides high-resolution three-dimensional views of the internal structures of printed parts. By analysing the CT scans, engineers can accurately locate and assess the size, shape, and distribution of defects inside the 3D printed part (see Fig. 1).
This information is crucial to understanding the root causes of defects and making necessary adjustments to the AM process, as well as for optimizing printing parameters such as laser power, scan speed, and layer thickness. By identifying and correcting the specific errors that occur during the printing process, manufacturers can improve the quality of printed parts, reduce material waste, and increase overall productivity.

One possible application in which industrial tomography appears to be the only applicable non-destructive diagnostic method is the analysis of lattice structures (see Fig. 2). Lattice structures are lightweight, strong three-dimensional grids composed of interconnected hollow cells.

They reduce weight without compromising strength, enabling material and weight savings in industrial applications. Lattice structures have the further goals of reducing production costs and time while realizing highly complex geometries that would be impossible to achieve with traditional methods.

However, lattice structures present several challenges in terms of creating a representative sample for mechanical and material characterization, and in terms of inspecting these structures using NDT methods. With industrial tomography any defects in the structure can be accurately detected, allowing considerations to be made to make the subsequent analytical path more meaningful.

Dimensional analysis

Dimensional accuracy is critical in AM because the printed parts must meet precise specifications and fit correctly into larger assemblies. Common dimensional deviations in additive manufacturing include warpage, shrinkage, and distortion. CT scanning helps identify these variations by comparing the scanned part with the original CAD model or design specifications. By quantifying dimensional deviations, engineers can make informed decisions about process adjustments. Here too, CT scanning provides a powerful dimensional analysis tool that allows engineers to non-destructively assess the dimensional accuracy of printed parts.

CT scanners capture high-resolution three-dimensional images of printed parts, enabling accurate measurement of both internal and external dimensions (see Fig. 3).

This feature is particularly useful for complex geometries that may be difficult to measure using conventional methods. By analysing the CT data, engineers can assess the dimensional accuracy of printed parts and identify any deviations from the intended design.

Virtual metrology

In addition to dimensional and defect analysis, CT scanning enables virtual metrology, eliminating the need for physical measurements. By extracting precise measurements from CT data, engineers can obtain accurate information on critical features such as hole diameters, wall thicknesses, and complex geometries.

The new ISO/ASTM 52902 standard provides guidelines for the qualification and calibration of AM machines, defining procedures and metrics to evaluate the performance and accuracy of AM systems and ensure consistency and reliability in the production of printed parts. TEC Eurolab has been studying this standard, and investigating its limitations. To do so, we designed and implemented a reference tool that includes the functionalities specified in the standard as well as others typical of AM technology.

Through this in-house project, we discovered, for example, that ISO/ASTM 52902 does not consider internal features, despite the fact that complex internal and external geometries are one of the main applications of additive manufacturing (see Fig. 4).

In addition to the possibilities offered by industrial tomography as a non-destructive inspection method, the generation of a complete 3D volume of the component provides a range of information that can be used as input for simulation activities, thus providing a link to traditional non-destructive diagnosis and design.

Considering these further possibilities offered by industrial tomography, TEC Eurolab developed two application examples. These are:

1) FEM simulation of real components with internal defects

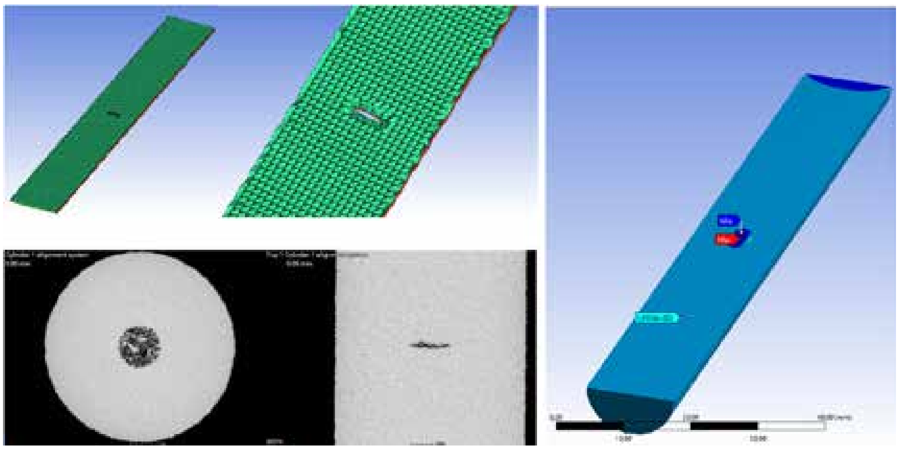
This provides an economical and efficient approach to assessing the impact of defects on the performance and reliability of expensive components.

By accurately modelling the presence and characteristics of defects, engineers can simulate the component's behaviour under various operating conditions and assess the potential risks associated with such defects. This information enables informed decisions to be made regarding the acceptability of the component and the need for further testing or remedial action. Ultimately, this application helps minimize waste and maximize the use of valuable components by providing a comprehensive assessment of their structural integrity and performance.

2) Artificial intelligence for defect analysis

Defect analysis in industrial environments is often reliant on trained and certified operators. However, the subjective interpretations and time-consuming nature of manual analysis can introduce inconsistencies and delays in the assessment process. To address this challenge within TEC Eurolab, we developed an AI-based solution that improves the objectivity of defect analysis, democratizes the process, and promotes sustainability.

Our AI solution uses advanced algorithms and machine learning techniques to analyse CT scan data and identify defects with high accuracy. By automating the



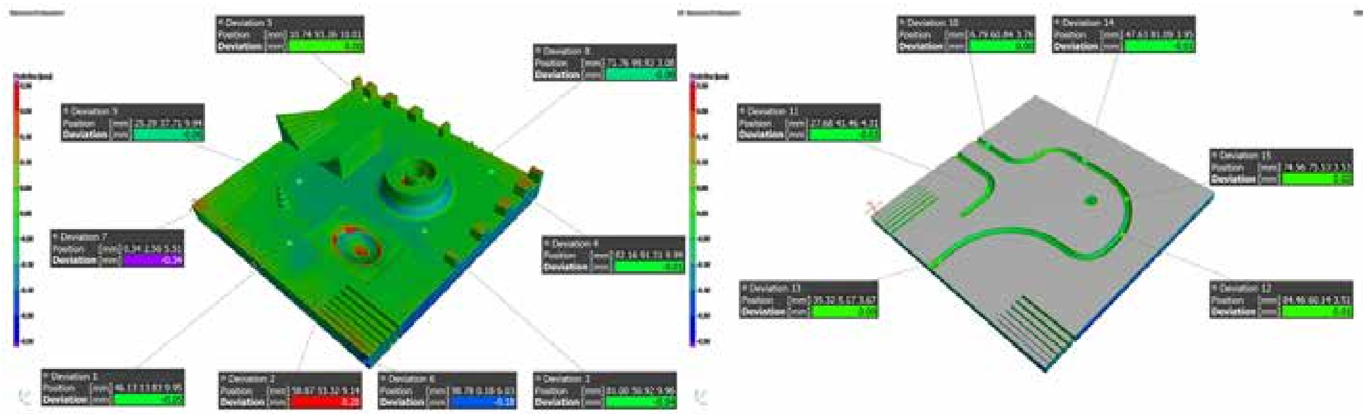


Fig. 4. Demonstrative component for defect analysis using computed tomography - example of an instrument for metrological verification. Note the realization of internal channels for dimensional verification of internal features that are difficult to detect with other NDT methods.

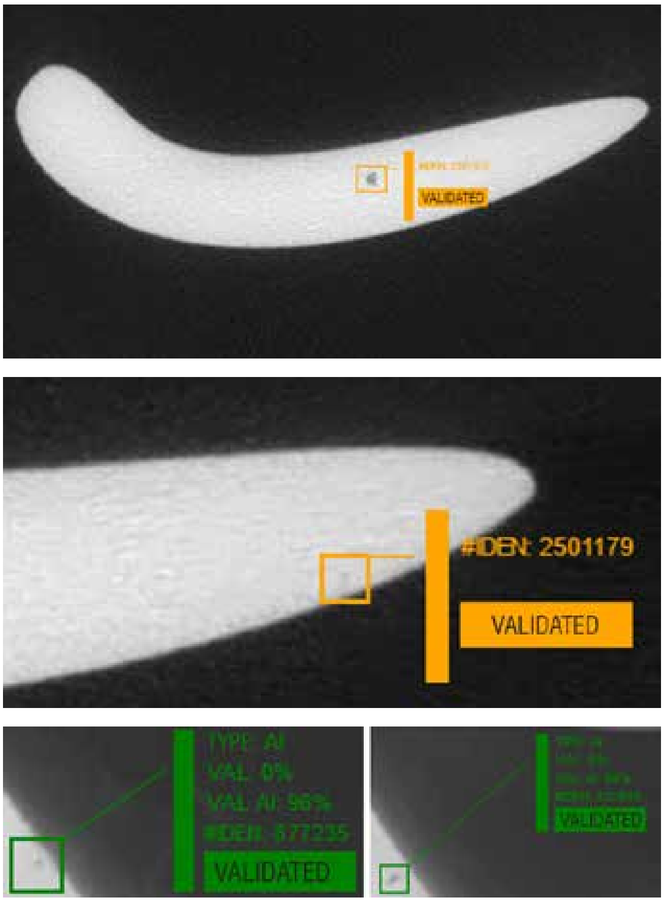


Fig. 5. Example of defect identification in component made of light alloy by additive manufacturing using artificial intelligence-based software

About TEC Eurolab

TEC Eurolab: empowering manufacturing industries with quality assurance and innovation. For more than three decades, TEC Eurolab has been consolidating its position as a trusted third-party industrial laboratory. Our extensive experience ranges from materials analysis and non-destructive testing to training, and certification for industries as diverse as automotive, aerospace, energy, biomedical, food, and cultural heritage. Accredited for the rigorous UNI CEI EN ISO/IEC 17025:2018, 17024:2012, and 17065:2012 standards, we epitomize competence, independence, and unwavering objectivity. Furthermore, our prestigious NADCAP accreditation and UNI EN 9100:2018 certification illustrate our proficiency in the aerospace and defence sectors.

At TEC Eurolab, we specialize in meticulously evaluating and qualifying materials and processes to optimize product performance. Our bespoke support ensures that every component and product surpasses project requirements. With a team of skilled professionals and innovative technologies at our disposal, we instil unwavering certainty in product quality, empowering companies to make informed decisions with the utmost confidence. TEC Eurolab offers accessible expertise and state-of-the-art tools, and works closely with customers to transform results into practical solutions that elevate their products to unparalleled prominence.

analysis process, we minimize the potential for human bias and ensure consistent and reliable results.

This not only improves the objectivity of defect analysis, but also reduces the dependence on the expertise of the individual operator. Furthermore, our AI-based solution significantly accelerates the process of defect analysis. What used to take days with manual analysis can now be done in a fraction of the time. This efficiency enables faster decision-making and supports timely action to correct identified defects, ultimately improving productivity and reducing downtime.

Conclusion

Industrial computed tomography (iCT) has emerged as a powerful and indispensable tool for non-destructive testing in additive manufacturing. This diagnostic technique addresses the unique challenges posed by AM components, enabling comprehensive defect and dimensional analysis. iCT excels in defect analysis for additive manufacturing components.

With high-resolution 3D visualizations, it accurately detects and characterizes defects like porosity, voids, cracks, and delamination. This information helps to understand root causes, thereby optimizing manufacturing, improving quality, reducing waste, and increasing productivity.

iCT is also particularly useful for analysing complex lattice structures, which are lightweight, robust three-dimensional lattices composed of interconnected hollow cells. Accurate detection of defects in these structures allows engineers to make informed decisions to ensure the integrity and functionality of the lattice components. iCT's dimensional analysis ability allows internal and external dimensions to be measured accurately, including complex geometries that are difficult for traditional methods. Engineers then compare scanned parts with CAD models to assess accuracy and make necessary manufacturing changes.

Furthermore, iCT enables virtual metrology by extracting precise measurements from CT data, providing accurate information on critical features such as hole diameters and wall thicknesses. This improves consistency, reliability, and quality control in the 3D printing of parts, increasing productivity.

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