# FROM VISION TO REALITY: PRACTICAL APPLICATIONS OF MIXED REALITY IN PRODUCTION, LOGISTICS, AND QUALITY

[1]Martin FOLTA, [2]Josef BRADÁČ, [3]Martin MEŠKO

[1, 2] *Škoda Auto University, Mladá Boleslav, Czech Republic, EU, martin.folta@savs.cz, josef.bradac@savs.cz*

[3] *cmoore.cz, s. r. o., Mladá Boleslav, Czech Republic, EU, martin.mesko@cmoore.cz*

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**Abstract**

The industrial landscape, including the automotive sector, is constantly striving for transformation in alignment with the principles of Industry 4.0 and broader digital transformation objectives. While numerous research papers elaborate on these concepts, they often do so in abstract terms, resulting in a notable gap between theory and actual implementation. Mixed reality tools, especially smart glasses, emerge as powerful catalysts for bridging this gap, primed to play a pivotal role in propelling industries towards the realization of Industry 4.0 and the evolution of smart factories. This paper delves into the potential applications of these advanced mixed reality tools within the industrial setting. By presenting specific use cases substantiated by proofs of concept, it offers tangible solutions poised for commercial deployment. The paper will further spotlight areas of practical application in production, logistics, and quality assurance, illuminating the path for genuine industrial transformation.

**Keywords:** Mixed reality, artificial vision, smart glasses, wearable technology, Industry 4.0, innovations, digitalization

## 1. INTRODUCTION AND LITERATURE REVIEW

The advent of Industry 4.0 has propelled a wave of digital transformation across various industrial landscapes, including the automotive sector. A plethora of research has been undertaken to explore the integration of emerging technologies, notably mixed reality tools such as smart glasses, in line with the objectives of Industry 4.0. These tools, hailed for their potential in bridging the theoretical and practical gap, present a pathway towards the tangible implementation of Industry 4.0 principles.

An article titled Integration of Mixed Reality to CFD in Industry 4.0: A Manufacturing Design Paradigm delve into the integration of Mixed Reality with Computational Fluid Dynamics (CFD) within the Industry 4.0 framework, emphasizing its potential in enhancing manufacturing design paradigms [1]. This notion aligns with the broader narrative of transforming traditional industries into smart industries by leveraging technologies like Extended Reality (XR) as discussed in a 2018 publication on ScienceDirect [2]. The manufacturing domain, particularly the automotive sector, has been at the forefront of this transformation, with a 2022 study underscoring the importance of Industry 4.0 in propelling research and advancements within this sector [3].

The application of Virtual Reality (VR) in the automotive field has also garnered attention. Role of VR is further explored in aiding product evaluation processes and process certification, signifying a step towards realizing the Industry 4.0 paradigm [4]. Additionally, the influence of Industry 4.0 extends beyond the automotive sector to supply chains and regional innovations in the aerospace and automotive industries, as explored by Hickie & Hickie [5].

The integration of Augmented Reality (AR) and Mixed Reality (MR) in Industry 4.0 has been a focal point in literature. A study on MDPI discusses the enlarged applicability of AR in improving productivity and enhancing user experience in industrial settings, resonating with the overarching objectives of Industry 4.0 [6]. Furthermore, an exploration by Springer highlights the increasing importance of MR technologies, particularly in bridging the gap between a completely real and a completely virtual environment [7].

On a broader spectrum, the discourse on Industry 4.0 underscores its holistic influence in fostering innovation and enhancing operational efficiencies across diverse industrial sectors. An article on TechTrends discusses Microsoft's strides in the Mixed Reality enterprise space, aiming to build Industry 4.0 efficiencies, which exemplifies the collaborative efforts between tech giants and industrial sectors in navigating the complexities of modern industrial operations [8].

The emergence of smart factories is central to the discussion of Industry 4.0. The literature reveals a consensus on the potential of mixed reality tools in facilitating the evolution of smart factories. The tangible benefits highlighted include marked improvements in industrial operations and economic advantages, which are pivotal in the commercial deployment of these transformative technologies.

The literature elucidates a promising trajectory for industrial transformation driven by the synergy between mixed reality tools and Industry 4.0 principles. The highlighted studies provide a robust foundation for further exploration into the practical application areas of these technologies in production, logistics, and quality assurance. Through a lens of interdisciplinary collaboration, the potential to maximize the transformative capabilities of these technologies is significantly amplified, paving the way for a new era of industrial operations aligned with the broader digital transformation objectives.

## 2. MIXED REALITY WITHIN INDUSTRIAL CONTEXT

The endeavour towards Industry 4.0 is synonymous with embracing digital technologies that propel industrial sectors into new realms of operational efficacy and innovative practices. Mixed Reality (MR), an amalgam of the digital and physical worlds, stands at the forefront of this transformation, promising to morph theoretical constructs into tangible industrial applications. This chapter unfurls the theoretical framework enveloping MR, juxtaposed against its counterparts, Virtual Reality (VR) and Augmented Reality (AR), and delves into its present-day industrial adoption, laying a cornerstone for the subsequent examination of practical use cases.

### 2.1. Theoretical baseline

The digital transformation wave, epitomized by Industry 4.0, has ushered industries into an era where the fusion of physical and digital realms is not only plausible but instrumental for enhanced operational efficacy. Central to this fusion are the technologies of Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), each with distinct capabilities and applications. This chapter endeavours to unfold the theoretical framework underpinning these realities, accentuating their differences and respective approaches, thereby laying a solid foundation for understanding the potential applications of MR in industrial settings.

#### Defining Virtual Reality (VR)

Virtual Reality (VR) is a digital experience that takes users away from the real world into a wholly immersive virtual environment. Through VR, users can interact with 3D digital elements using specialized headsets and input devices. However, the interaction is confined within the digital domain, with no engagement with the physical world. VR's immersive nature is exemplary for simulation-based training, design, and visualization, where a complete detachment from the physical world is desired.

#### Understanding Augmented Reality (AR)

Augmented Reality (AR), unlike VR, does not detach users from their physical surroundings. Instead, it overlays digital information—such as images, texts, or animations—onto the real world. AR can be experienced with more straightforward devices like smartphones and tablets, besides specialized AR glasses.

However, the interaction between the digital overlays and the physical world is limited or non-existent in AR. Industries find AR beneficial for tasks that require real-time information overlay, such as maintenance, repair, and training.

**Unveiling Mixed Reality (MR)**

Mixed Reality (MR) is the hybrid of VR and AR, encapsulating the immersive nature of VR and the real-world awareness of AR. MR not only overlays digital content onto the real world but allows for interaction between the two realms. Through MR, digital content can respond to, and interact with, the physical world in real-time. This is achieved through advanced sensors and cameras embedded in MR devices like smart glasses. MR holds immense promise for industries, extending capabilities for real-time data analysis, collaboration, and hands-free operation, which are pivotal for modern-day industrial applications.

The panorama of immersive technologies is a continuum, with Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) as its quintessence as also shown in **Figure 1**. At one extreme, VR ensnares users in a wholly digital environment, disengaging them from the physical realm. Contrarily, AR retains the connection with the physical world but overlays digital content upon it, facilitating a modest level of interaction with the digital overlays. Nestled between these extremes, MR embodies the merits of both, forging a realm where digital and physical entities interact in real-time.

The crux of Mixed Reality lies in its capacity to blend the digital and physical worlds seamlessly. Unlike VR, which necessitates a complete immersion into a digital environment, or AR, which primarily overlays digital information onto the physical world, MR enables a two-way interaction between the two realms. This interaction, orchestrated through advanced wearable devices like smart glasses, extends the user's perception and interaction capabilities beyond the physical world into a digitally augmented environment. These wearable devices, equipped with sensors and cameras, capture the physical environment, and superimpose digital information onto it, allowing users to interact with digital content in the context of the physical world.

The theoretical essence of MR is further enriched by its alignment with the principles of artificial vision and real-time data processing. The underpinning technology enables the recognition and tracking of physical objects, and the rendering of digital content correspondingly. This real-time feedback loop is what sets MR apart, making it a potent tool for complex industrial applications where real-time data, analytics, and collaboration are pivotal.

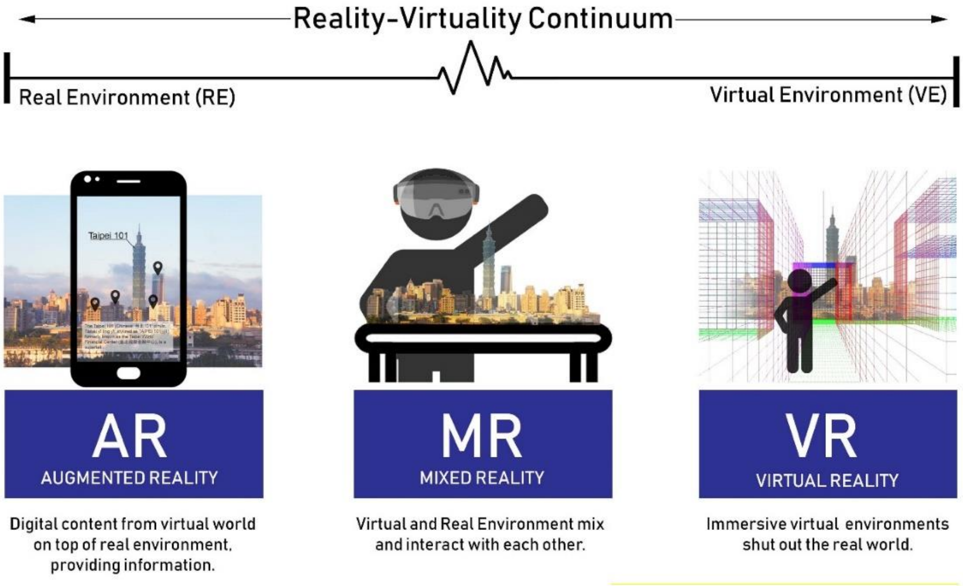


**Figure 1** Differences between AR, VR and MR [9]

Furthermore, the concept of MR is not confined to visual augmentation alone; it envelops other sensory augmentations like auditory and haptic feedback, providing a more holistic immersive experience. The theoretical exploration of MR opens a window to a myriad of possibilities, transcending the boundaries of traditional human-computer interaction paradigms and paving the way for more intuitive, context-aware interactions within industrial settings.

As we traverse the continuum of immersive technologies, it's imperative to delineate the distinct characteristics and capabilities of Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). This comparative analysis aims to juxtapose these technologies across various dimensions, providing a nuanced understanding of their applicability and requisites. Through this lens, we will elucidate how each technology aligns with industrial needs and the extent to which they can be harnessed for enhanced operational efficacy.

**Comparative Analysis**

**Level of Immersion:**

- VR provides a fully immersive digital environment.
- AR provides partial immersion by overlaying digital content on the real world.
- MR offers a balanced immersion, allowing interaction with both digital and physical elements.

**Hardware Requirements:**

- VR necessitates specialized headsets and often additional input devices.
- AR can be experienced with common smart devices or specialized glasses.
- MR requires advanced hardware like smart glasses equipped with sensors and cameras for a more interactive experience.

**Interaction Paradigm:**

- VR interaction is confined within the digital domain.
- AR provides limited interaction with digital overlays.
- MR facilitates a two-way interaction between the digital and physical worlds.

**Industrial Applicability:**

- VR is suited for simulation and training.
- AR is beneficial for information overlay and guidance.
- MR, with its interactive nature, holds broader applicability in real-time data analysis, remote collaboration, and operational efficiency.

Understanding the nuances between VR, AR, and MR is instrumental in recognizing the potential and limitations of each within an industrial context. While VR and AR have their merits, it is MR that stands at the forefront of bridging digital capabilities with physical operations, rendering a new dimension to how industries can leverage digital technology for tangible benefits. This theoretical delineation serves as a steppingstone for delving into the practical applications and challenges of MR in subsequent chapters, thereby inching closer to realizing the vision of digital transformation in industries.

Despite its potential, the road to MR adoption is laden with challenges. Technical limitations, high costs of implementation, and a lack of standardized frameworks are some of the hurdles that need to be navigated. Moreover, the human factor – acceptance, and adaptation to this new interaction paradigm is crucial for successful implementation.

### 2.2. Current situation of use of mixed reality within automotive industry

The journey of MR from conceptualization to industrial adoption is in its infancy, albeit burgeoning. The potential of MR in revolutionizing industrial practices is being recognized, yet its adoption is paced by several factors.

In production environments, MR is being piloted to provide real-time visual guidance to operators, thereby minimizing errors and improving efficiency. The ability of MR to overlay digital instructions onto physical objects in real-time is a boon for complex assembly and maintenance tasks. For instance, MR can guide operators through assembly processes by displaying step-by-step instructions directly onto the workpieces.

The logistics sector too sees a glimmer of transformation with MR. Route optimization, real-time inventory tracking, and spatial planning are areas where MR is being explored. By visualizing data and analytics in real-time, logistics personnel can make informed decisions swiftly, optimizing the flow of materials and finished goods.

Quality assurance, a critical aspect of industrial operations, is also under the lens of MR transformation. Real-time monitoring and analysis enabled by MR ensure adherence to quality standards, thus mitigating risks associated with defects and non-compliance.

However, the road to widespread adoption is not devoid of hurdles. High implementation costs, lack of standardization, and technical challenges like latency and accurate real-world tracking are significant barriers. Additionally, the readiness of the workforce to adapt to new interaction paradigms and the imperative for robust data security measures are other considerations slowing the pace of MR adoption.

Nonetheless, with technological advancements and the resolution of prevailing challenges, the industrial adoption of MR is poised for acceleration. The current explorations and pilot implementations are mere precursors to a broader transformation that MR is slated to bring to the industrial domain, aligning with the overarching vision of Industry 4.0.

The journey of augmented reality (AR) and by extension, mixed reality (MR) in the industrial sector has been evolving over the last decade. 2023 marks the 10-year anniversary of Google's infamous Google Glass launch which kickstarted the era of commercial AR headsets. However, the adoption rate has not met expectations initially due to limitations in the first generation of AR devices (2013-2018). By 2019, advancements in technology led to the launch of the second generation of AR devices aiming to resolve the initial pain points and push towards more widespread adoption. Despite these advancements, as of now, less than one in six enterprises have rolled out AR/MR technology in some form.

By 2024, the combined market for AR, VR, and MR is expected to reach nearly USD 300 billion, indicating a substantial investment by businesses in these technologies (see **Figure 2**).

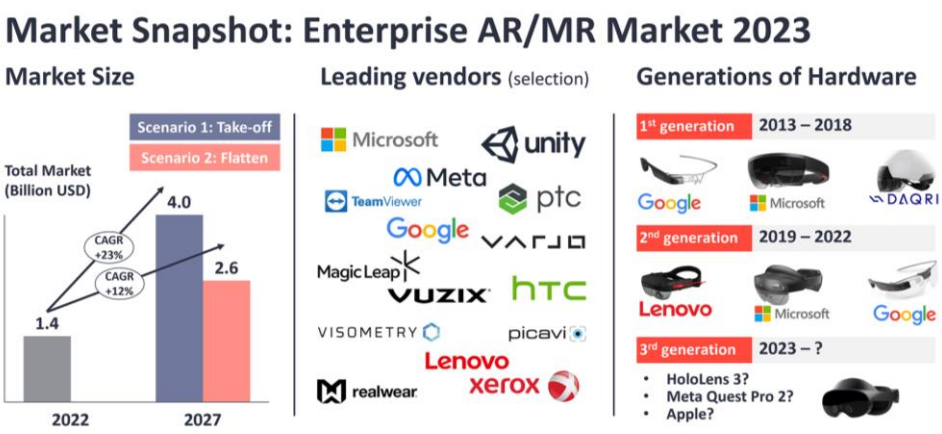


**Figure 2** AR, VR and MR market snapshot [10]

The adoption and usage of Mixed Reality (MR) technology in the industrial sector are evidently on an upward trajectory, as deduced from various market analyses.

Mixed Reality is being employed to address frontline worker training, support, and knowledge transfer across industries. It helps in quickly resolving issues with remote support and collaboration, which is crucial as the average manufacturer faces over 800 hours of equipment downtime a year.

In summation, the statistical data and market analyses provide a compelling narrative of MR's promising potential in driving industrial innovation and operational efficiency. As technological barriers are surmounted and more success stories emerge from pilot implementations, the industrial sector is likely to witness a more widespread adoption of MR, making it a cornerstone of the next industrial revolution.

## 3. PRACTICAL APPLICATIONS AND USES CASES

As industries stride towards the digital frontier, the application of Mixed Reality (MR) holds the promise of transforming theoretical concepts into practical solutions. The previous chapter laid the theoretical foundation of MR, presenting a clear distinction from its counterparts, VR and AR. This chapter unfolds the practical applications and use cases of MR in the industrial sector, shedding light on its implementation and the barriers faced in wide-scale adoption. This exploration aims to provide a pragmatic perspective on the potential of MR in driving industrial innovation while addressing the existing challenges.

### 3.1. Use cases ready out of the box

This section explores a selection of Mixed Reality (MR) applications that are prepared for immediate deployment within industrial settings, specifically focusing on production, logistics, and quality assurance domains. These 'ready out of the box' use cases exemplify the ease of integrating MR technology with existing operational frameworks, portraying its capability to deliver instant value in addressing real-world challenges and enhancing process efficiencies. Through a review of such practical applications, we underscore the tangible benefits, and the advancements MR brings to the contemporary industrial ecosystem.

#### Worker Training and Guidance for Complex Assembly Operations

MR devices guide workers step-by-step through standardized and logically organized assembly processes. The technology provides textual, pictorial, visual, or audio instructions and feedback, ensuring correct, standardized, and repeatable assembly procedures. This application significantly reduces the probability of error and can be used for both training and continuous guidance of workers during assembly tasks.

#### Warehouse picking

Mixed Reality (MR) can significantly optimize warehouse picking operations. Through MR headsets, workers can receive real-time visual guidance on picking tasks, ensuring accurate and efficient execution. The system can highlight the exact location of items to be picked, thus minimizing errors and reducing the time spent on each task.

#### Hands-free Logistic Processes

MR enables a hands-free interaction paradigm, which is especially beneficial in logistics where personnel often need to handle materials. By visualizing information through MR headsets, workers can access necessary data and instructions without the need to operate handheld devices, thus enhancing efficiency and safety.

**Enriched Logistic Processes**

Broadly, MR enriches logistic processes by providing a visual, interactive platform for real-time data access, collaboration, and decision-making. Whether it's route optimization, inventory management, or spatial planning, MR provides a holistic, interactive, and real-time solution, driving significant improvements in operational efficiency.

**Quality Control**

Assisted quality control is another application where MR shines. MR devices alert workers to critical points, guiding them through the checking process while recording the completed steps and the detected data. This form of inspection can be applied at any stage of the production process, and the data collected is stored, interpreted, and can be used to generate inspection reports.

**Tool changes**

Post the completion of a production batch, MR aids in reassigning the assembly station to a different product type by ensuring standard procedures are followed. It provides detailed instructions and documentation to workers, guiding them through a predefined standard procedure, which minimizes the risk of omissions and accelerates the reassembly process.

**Maintenance and repairs**

Defined Total Productive Maintenance (TPM) steps performed at the beginning or end of each production shift are guided by MR. The technology provides clear instructions at specific points along the production line, ensuring smooth execution of TPM within the stipulated time.

During breakdowns or planned maintenance, maintenance personnel can leverage MR to access repair plans, machine documentation, drawings, manuals, and other necessary information in real-time. MR facilitates remote communication with experts for solving complicated problems, thus minimizing downtime.

**Enhanced Efficiency and Productivity**

The outlined MR applications lead to higher efficiency and availability of production lines/equipment, lower scrap rates, reduced repair times, and effective Total Productive Maintenance (TPM). By eliminating performance discrepancies between experienced and new employees, MR technology significantly contributes to making workers' jobs easier and more efficient.

These applications reflect a breadth of possibilities that MR offers to the industrial sector, potentially catalysing the transition towards more digitized and efficient operational paradigms.

### 3.2. Implementation into the praxis

MR, with its ability to merge digital information with the physical world, offers a realm of practical applications across various industrial domains. Its implementation transcends conventional digital interfaces, bringing a new dimension to how operations are conducted, monitored, and optimized.

In production environments, MR facilitates an interactive guidance system for operators. Through smart glasses or other wearable devices, operators receive real-time visual instructions overlaid on physical objects, aiding in complex assembly tasks. This interactive guidance reduces the learning curve, minimizes errors, and accelerates the production process.

Furthermore, MR is a boon for maintenance and repair operations. Technicians can access digital manuals and schematics overlaid on the equipment, receiving real-time guidance to troubleshoot and repair.

Additionally, remote experts can visualize the same scenario as the on-site technicians through MR, providing real-time assistance and expertise, thus reducing downtime significantly.

In the realm of logistics, MR optimizes route planning and inventory management. By visualizing real-time data and analytics, logistics personnel can make informed decisions swiftly. Moreover, MR facilitates spatial planning, allowing for efficient utilization of storage spaces and streamlined material flow.

Quality assurance also gets a facelift with MR. Real-time monitoring and analysis ensure adherence to quality standards, enabling immediate corrective actions whenever deviations are detected. This proactive approach to quality assurance minimizes risks and ensures compliance with regulatory standards.

Training and skill development are other areas where MR is making strides. By creating an interactive, immersive training environment, MR accelerates the learning process, ensuring that the workforce is well-equipped with the necessary skills to meet the evolving demands of the industry.

**Potential Applications in Industrial Settings:**

The integration of MR in industries heralds a new era of operational efficiency and enhanced decision-making. In production lines, MR facilitates real-time analytics, guiding operators with visual instructions which significantly mitigate the chances of errors. In logistics, route optimization, and real-time inventory management become achievable, ensuring timely deliveries, and minimizing carrying costs. Quality assurance too gets a facelift with MR, enabling real-time monitoring and adherence to stringent quality standards.

**Interaction Paradigms:**

One of the hallmarks of MR is its interactive paradigm. Unlike traditional interfaces, MR, through wearable technology, provides a hands-free, intuitive interaction medium. This is particularly beneficial in industrial environments where operators are engaged with physical tasks, allowing them to access digital information effortlessly without hampering the workflow.

**Remote Collaboration and Expertise Sharing:**

In a globalized industrial landscape, expertise is scattered across geographies. MR serves as a bridge, enabling real-time collaboration between local and remote teams. Experts, miles away, can provide real-time guidance and support, drastically reducing downtime and enhancing problem-solving.

### 3.3. Barriers to Widespread Adoption

Despite the promising prospects, several barriers hinder the widespread adoption of MR in industries. One primary concern is the high cost of implementation. The acquisition of advanced hardware, software, and the necessary infrastructure for MR can be financially burdensome, especially for small to medium-sized enterprises.

Technical limitations also pose significant challenges. The accuracy and reliability of MR systems are paramount, and any discrepancy in real-world tracking or digital overlay can lead to erroneous decisions and operations. Moreover, latency issues can adversely impact real-time interactions, which is a critical requirement for many industrial applications of MR.

The lack of standardization and interoperability among different MR systems is another hurdle. With various vendors offering disparate MR solutions, the absence of standardized frameworks and protocols hampers seamless integration and scalability.

Furthermore, data security and privacy concerns are at the forefront, given the extensive data collection and sharing involved in MR applications. Ensuring robust data encryption and privacy compliance is imperative to build trust and ensure legal compliance.

Lastly, the readiness of the workforce to adapt to the new interaction paradigms brought about by MR is crucial. Change management, training, and ensuring a smooth transition to MR-based operations are necessary to foster acceptance and maximize the benefits derived from MR implementations.

The barriers outlined underscore the necessity for a collaborative effort among industry stakeholders, technology vendors, and regulatory bodies to address the challenges and pave the way for the broader adoption of MR, ultimately realizing the vision of a digitally augmented industrial landscape.

## 4. RECOMMENDATION AND CONCLUSION

Embracing the future requires both vision and actionable steps. As industries consider integrating mixed reality tools, a roadmap becomes essential. From phased implementation to continuous training, various strategies can ensure the successful adoption of mixed reality tools. These strategies consider both the technical and human aspects of integration.

While this research has delved deep into the current applications and implications of mixed reality, the field is ever evolving. Pointers for future research areas and potential avenues of exploration are highlighted, ensuring that the journey toward full industrial transformation continues unabated.

As we navigate the labyrinth of industrial transformation, the beacon of mixed reality, especially tools like smart glasses, illuminates our path. From the promises they hold to the challenges they present, this journey with mixed reality tools has been both enlightening and thought-provoking.

Reflecting on the discussions from previous chapters, this section aims to encapsulate the essence of the transformation underway. It reaffirms the pivotal role of mixed reality in the realization of Industry 4.0 and looks ahead to the future possibilities that remain unexplored.

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