The Many Forms of XR In Manufacturing

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SUMMARY & CONCLUSIONS

In recent years the terms Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and Extended Reality (XR), have come to conjure thoughts of bulky, uncomfortable head mounted displays (HMDs) or high-tech elaborate and expensive rooms filled with large screen display walls, requiring special glasses and motion tracking equipment. While many XR applications require such devices, there are some which do not. This paper examines innovative use cases and implementations of XR.

For this paper, XR is defined as an umbrella term which describes technologies that combine the physical world with digital elements to create immersive experiences. In this definition XR covers the full spectrum of devices and implementations from VR to AR, employing different forms of advanced visualization techniques, going beyond HMDs.

The work described herein was motivated by the observation that not all industries can acquire and vet the use of a constantly changing environment of headsets, peripherals, and costly video cards. Economically leveraging XR techniques requires an understanding of how to use existing technology to create XR environments.

This paper begins with an introduction to XR. In section 2, successful use-cases of XR in manufacturing and industry are discussed. Section 3 presents how XR, using large-scale displays and headsets, aids in establishing reliability and maintainability of products and process throughout the product lifecycle. Section 3 also offers examples showing how an understanding of large-scale XR systems and headsets leads to a wider, and less expensive, range of applications and use cases. Section 4 offers thoughts on the future of XR.

In summary, this paper provides examples of using inexpensive displays and computer systems to build XR environments. Throughout the paper, examples and references show how XR can create opportunities to improve manufacturing processes, including those of reliability and maintainability, and convey that to business leaders and customers. In the end, small creative efforts can yield large amounts of support. From the small efforts, larger XR efforts might then be pursued.

1 INTRODUCTION

XR technologies are fundamental to Industry 4.0 advancements. They merge the physical and digital world, creating new knowledge in real-time, decision making, and product and process innovation [1]. Different modalities of virtuality, including VR, AR, and MR, have been successfully used in many industries [2][3], including manufacturing [4][5].

Related to XR technologies are digital twins. The use of digital twins can be broadly defined as the integration of data between a physical machine and its digital replica in the virtual world [2]. This can be achieved using 3D computer models, pictures, simulations, or anything that represents the physical behavior of the virtual world. Such twins are useful in XR.

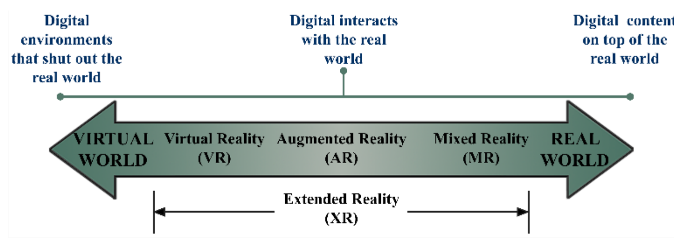

Figure 1: The XR spectrum. Source: Primary.

VR and AR fall on opposite ends of the XR spectrum. Headsets, or HMDs, are commonly used to create VR environments. Large-scale displays, or CAVE systems [6], can also be used. VR headsets are successful in cases where a near 360º viewing range is more important for immersion than resolution. Large-scale displays are successful when resolution and group presence are higher priority than immersion [7]. Both VR options can be costly. HMDs range in price from several hundred to thousands of dollars per headset. High-quality largescale systems range into millions of dollars. HMDs may also introduce costly security and maintenance fees as they are often stand-alone, on-network devices which can quickly become outdated and out of service.

On the AR side of the spectrum more implementation options exist, but most applications use HMDs. This, as noted, has costs and risks associated with using such technology. So, while the potential for XR in manufacturing remains high, the challenges in adopting such technology and the financial risk and policy change requirements can be daunting [8][9].

Fortunately, not all XR applications require HMDs or large-scale displays. Understanding the how-and-why of merging the physical with the digital is fundamental in effective use of XR concepts. This understanding leads to a broader range of applications and may significantly improve user experience and user interface design. Innovative application of this understanding can provide opportunities to explore XR usage without full-scale buy-in of expensive or complex systems.

The following sections provide examples of XR implementations. They demonstrate multiple ways to create and use XR environments. Discussion addresses the questions of why to use them, and how to go from expensive and complex to less complicated and less expensive creation by focusing on what is needed. Within each example is the ability to create opportunities to better design, establish, improve, or convey the reliability and maintainability of manufacturing processes to business leaders and customers.

2 XR SUCCESS IN MANUFACTURING

XR has taken many forms in manufacturing. Within the context of industry 4.0, XR can improve assembly skills, task and decision-making abilities, and spatial cognition and visualization skills [10]. Almost every phase of manufacturing has found a use-case for XR.

In the assembly phase, AR can provide workers visual instructions on a task, superimposing virtual objects onto the real world. This enhances the worker's ability to make better decisions, reduce errors, and reduce reliance on paper-based documents and guides [2][11]. An example of this is found in assembly methods using a pick-by-light system [12]. In this system a projector system is used to assist workers in selecting and assembling pieces.

XR assists manufacturing maintenance in decreasing the chance of machine failures, reducing production costs, and increasing equipment availability, utilization, and reliability. For example, AR can provide digital overlays of diagnostic information onto the equipment being examined, allowing technicians to quickly identify and address issues. Such AR enhancements have been shown to reduce downtime, minimize disruptions in production, and improve the workflow of maintenance operations [9][13][14]. VR also has proven useful by enhancing the documentation review and risk assessment processes. This is particularly useful when the reviewing parties are geographically scattered [15]. Additionally, when properly planned, such VR collaborations can identify and improve the digital data and models to use in AR enhancements. This encourages development and reuse of digital, 3D, models throughout the product life cycle. This aligns well with digital twin concepts and implementations.

These gains extend into automation. Like AR maintenance techniques, AR applications can overlay digital data used in assembly to integrate into cyber-physical systems of automation platforms. For example, an AR application can direct humans to stay coordinated with an automated robotic system. The AR display provides workers with step-by-step instructions and a system to visually monitor the state of robotic machines [16]. Thus, the workers perform tasks in tandem with the machines and remain aware of machine states and production schedules. XR may also enhance automation safety by providing virtual test environments for robotic movement or verifying physical space requirements prior to building the system. These applications pair nicely with reality capture and motion capture efforts.

XR applications also reach into the realm of training, offering immersive learning environments and simulations for employees. These allow employees to practice and learn required skills with minimal risk and no downtime of working systems [17][18][19].

Remote collaboration is another area which can greatly benefit from XR applications. This is done by using XR environments to provide real-time data sharing, interaction among remote teams, and enhance communication [5][20].

Quality control [21], supply chain management [22], and design and prototyping [23] are also areas of manufacturing which can benefit from XR applications. In sum, almost every phase of manufacturing has found a use-case for XR. Many of these examples help improve the reliability and maintainability of products throughout the product lifecycle. As mentioned, however, incorporating them into actual practice remains challenging.

3 XR THROUGOUT THE LIFECYCLE, BIG AND SMALL

This section outlines a story of discovery. The intent is to share experiences in achieving successful outcomes, such as those already described. Every effort has its own unique challenges and can be leveraged as a learning opportunity. The story begins with a large-scale display and an immersive area. Over a decade of use has proven such an area can empower employees to use XR technology for presentations and meetings for any phase of manufacturing, from design, to marketing, to production, to shipping, to training, and into maintenance. Through such the quality and reliability of products and processes has been improved.

These improvements define the why-use-XR. Beyond those cited, there are many more papers explaining the gains of XR. In this section the focus is on how-to-use-XR. The examples here and already mentioned should illustrate there are many ways to achieve those gains, not all require vast amounts of investment or knowledge. Most require an awareness of goals, and a modest amount of creativity. Sometimes only a small effort is needed to gain a large amount of support. These examples will hopefully inspire such efforts and lead to successes across a diverse range of businesses and industries.

3.1 *Immersive Design Centers*

Immersive Design Centers (IDCs) are areas created to empower employees to use cutting-edge visualization and communication technologies. They vary in implementation but minimally include a large display area supporting stereoscopic views, space for a thirty-person audience, assorted cameras, speakers, and microphones for telecommunications, along with sensors, peripherals, and tracking devices for interactive capabilities. Most IDCs also provide personnel, hardware, software, and services to support additional XR devices, content creation, usage training, and reality capture efforts.

Figure 2: Immersive Design Center, Raytheon, McKinney, TX. Source: Primary.

Some of the past gains of Raytheon IDCs have been documented [24][25]. They have been used from the conceptual planning of product design to production operations and maintenance services. They have proven repeatedly that XR technologies provide holistic support to businesses throughout the entire product life cycle. IDCs are large, expensive, and require skill and experience to create and run effectively. While the authors of this paper have made significant strides to reduce the complexity of usage, most IDCs still require a specialized team to support them. The initial cost of building IDCs is large, but time has shown they produce enough ROI, and other gains, to cover such costs.

Many of the gains come from having a supporting team. The authors have been members of multiple teams, in different areas, spanning decades. The IDCs are just one way to introduce and use XR technologies. In basic design they are CAVE-like systems. They can support a multitude of efforts and use cases, and as stated offer holistic support throughout the entire product life cycle. But sometimes big is not the best, nor affordable. Supporting people in the use of XR for many years has allowed the authors opportunities to discover and explore other options.

3.2 *Portable Systems*

Sometimes people cannot come to the room, so the room must go to them. That was the thought which led to several extensions out of the IDC.

VirtualWorx™ was one of the extension technologies. This technology is designed to assist in remote maintenance and inspection activities [26].

Another XR technology extension of the IDCs was a simple portable system. It was termed a Backpack Visualization System (BVS). This was composed of a basic laser projector which supported stereoscopic display, some active stereoscopic glasses, and a small computer or laptop with a high-end graphics card. These items plus supporting software, cables, and instructions all fit into a small backpack. This assemblage made a portable CAVE-like system, that could be carried on a plane or shipped. Each system could then support XR based presentations almost anywhere. If needed, the system could connect any remote user, or small set of users, back to an IDC for group collaborations in XR environments. It was also possible to use multiple mini projectors to create larger displays. No headsets were needed, only a single computer. This allowed much easier conformance to security and protocol compliance.

Figure 3: VirtualWorx™ remote support system. Source: Primary.

The BVS also described and proved that should the need arise, the typical conference room could be upgraded to a small IDC area. To do so is just a matter of selecting a stereoscopic enabled projector, a good graphics card, and some active stereoscopic glasses. The total cost is less than $10,000. Much less than a full-scale IDC.

3.3 *Pop-up Systems*

Sometimes demos need to be big, but only for a short period of time. Sometimes words are not enough, and painting a picture is the only way to show how good the idea really is. Planning and documenting take time, and there never is time to build examples. If only there were a window into the future, then it would be easy to see how it all goes together.

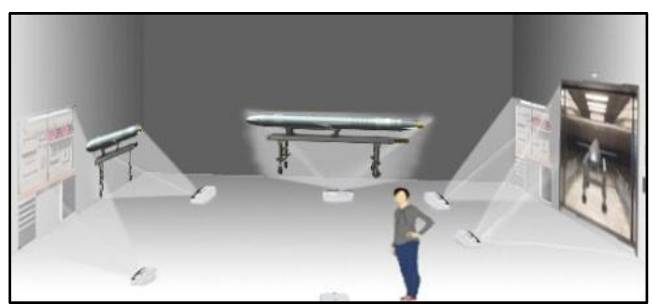

Figure 4: XR visualization of production space. Source: Primary.

Here the need to visualize work done is geared toward sales, production flow, and facilities planning. When proposing new activities or upgrades a large amount of thought and work is spent on planning, often in the digital world. Models are generated, production flow is rendered, facility space and usage are calculated. Demonstrating how that planning comes together can be difficult using a basic PowerPoint presentation.

Assume, the goal of the presentation is to show a product's production space before making a proposal. The models have been generated, the plan is in place, but physically there is just an empty space. The need is to establish, and vividly show, a competitive discriminator. For this a very simple usage of XR can be worth millions and cost almost nothing.

For example, using small projectors placed strategically around a room, it is possible to display products and workstations at room-scale. While this is not stereoscopic, it is more than sufficient to give a feeling for how the room layout will work. The cost is negligible as the models to display should already be developed, and mini projectors with a 4k resolution and around 8000 lumens are not expensive. The supporting computer system can be one or two computers. Each having the ability to use 2 or 3 projectors at a time, which using today's technology can be done using USB outputs.

This display can be further enhanced if the work area has a large window into the area, or perhaps a garage-door-style entry. Inexpensive transparent film can be adhered to the windowed area and then projected onto from within the room. Thus, on approach to the area, visitors can look inside the room and see what it would appear like before entering. This requires some window film, a projector, a computer, and some skill in positioning objects at the correct perspective for display. While brilliant in effect, the cost is mostly creativity. It is basically a reapplication of film and theater concepts to business, using XR applications.

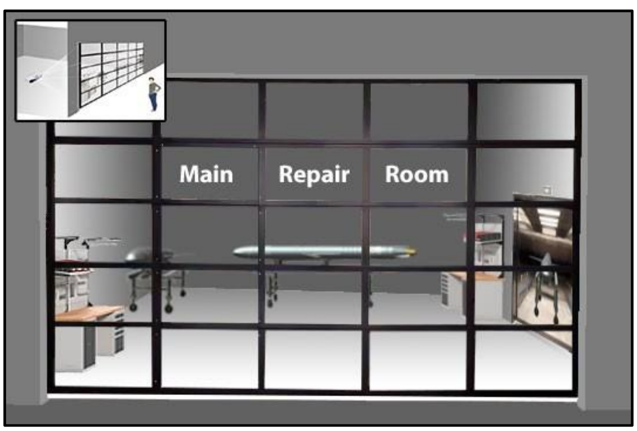

Figure 5: XR window into a proposed production space. Source: Primary.

Hidden in this example is another subtle enhancement. The displays shown can be a combination of real-world and computer-generated objects. Also, they are not limited to static images, they can be video as well. For example, the elevator is a real video of an elevator opening and closing. Composited into the video is a product model. This demonstrates how the product would fit into an existing real-world elevator. The animation further enhances the immersion of the effect.

Figure 6: Mixing video with computer generated models. Source: Primary.

3.4 *Looking Outward*

Not all things are inside. Sometimes there is a window to the outside, but all the information is elsewhere. It would be nice to see it all together.

Figure 7: Monitor provides XR view to the outside world. Source: Primary.

This last example was motivated by a need to display information on a physical view of the outside world. The desired outcome was to display information directly on a window looking out. There are many complicated and expensive ways to project information onto a window, looking outside. However, doing so is not always necessary, based on requirements. A significantly easier way to achieve a similar result is to use a webcam, a computer, and a large portable monitor.

Using this setup, the webcam points out the window of interest. It is plugged into a computer which sits below a large screen monitor. The computer is a standard asset with all the necessary security and communication protocols installed. It either produces the desired output information or can access the information over a network. This information is composited, or overlaid, onto the video stream from the webcam. The resulting image is then a view of the outside world with the desired information. The system is then placed physically in such a way as the horizon line of the monitor's display lines up with the horizon line when looking out the physical window.

There are some details to make this system work optimally, but it is less expensive and easier to implement than most other options. It is an excellent example of using simple, existing equipment to achieve XR gains.

4 FUTURE XR

XR environments have been used from the conceptual planning of product design to production operations and maintenance services. They provide holistic support to businesses throughout the entire product life cycle. This paper has provided examples of using inexpensive displays and computer systems to build XR environments. Throughout the paper, examples and references show how XR can create opportunities to improve reliability and maintainability in manufacturing and convey such gains to business leaders and customers.

The future of XR will extend into the realm of Artificial Intelligence (AI), reality capture, and robotics. Achieving success will be nontrivial. It will require funding, dedication and perseverance. While some may have the ability to go big from the beginning others may choose smaller investments. Yet, from small creative efforts larger XR efforts might then be pursued. The possibilities are virtually endless.

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Brent Dingle earned a Ph.D. in Computer Science and a master's in mathematics from Texas A&M University. His bachelor's degree was awarded by Bradley University. For nearly a decade he was a Sr. Engr. and Development Lead in the Immersive Design Center at Raytheon in McKinney. He has over 20 years of experience in Modeling, Simulation, and Analysis. He is a member of the ACM and IEEE. Much of Brent's current work focusses on image acquisition, processing, and display. In the past he worked in Game Design and Development, with two published titles. For several years, he was an Assistant Professor at the University of Wisconsin – Stout. His interests include user interfaces, XR, AI, and advanced visualization. In these areas, he seeks to understand and explore all aspects of perception and reality, particularly the interaction and visualization thereof.

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