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The Industry of the Future: From Industry 4.0 to Industry 5.0 – Integration of Humans and Technology: New Technologies

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Augmented Reality in Industry 4.0/5.0

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Abstract: *As the industry continues to evolve, Augmented Reality (AR) will play a key role in shaping the future of manufacturing. The transition from Industry 4.0 to Industry 5.0 represents a shift from a purely technology-based approach to one that integrates human-centric values, sustainability, and advanced human-machine collaboration. In this evolution, AR is a technology that bridges the gap between the two industrial paradigms. AR is making a difference in the manufacturing sector by improving efficiency, accuracy, and safety. Using a device that supports this technology, engineers and operators have the ability to access information and instructions in real time, reducing the need for hard copy manuals and other types of training materials. AR also enables experts to provide guidance and troubleshoot from any location.*
This paper analyzes AR as one of the most useful techniques for virtualizing the physical world in industry. It also provides descriptions of some of the software packages used in the development of AR systems in manufacturing environments and which have been used in the development of applications for recognizing machine components.

Keywords: *Industry 4.0/5.0,Augmented Reality, Unity, PTC Vuforia*

1. Introduction

Augmented Reality (AR) is a technology that, with the use of appropriate equipment and applications, overlays the visible (real, physical) world with a layer of digital content [1]. This is an auxiliary system used in logistics, maintenance, assembly, etc. (*Assisted Operator*). AR is a direct or indirect representation of the physical environment in the real world that is enhanced/supplemented by adding virtual digital information. AR is an interactive technology in 3D format and combines real and virtual objects. AR aims to help the user by displaying virtual information, not only in the user immediate environment, but also enables any indirect view of the real world environment. AR enhances the user perception and interaction with the real world [2].AR can also be used to augment the user senses through sensory substitution, using audio or visual signals. Virtual objects integrated into the real environment display information that the user cannot directly register with his senses. Information transmitted by virtual objects can e.g. to help the worker when performing activities in the production process [3]. AR can be applied in

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plant maintenance, providing information on the condition of machines, wear of tools, necessary servicing of equipment, etc.
When we talk about AR and its ability to integrate digital information into the real world, there are certain prerequisites that enable this technology (hardware and software conditions) [4,5]. The user, through virtual or augmented reality glassesor the screen of a phone or tablet, sees an image of the real world captured by a camera, on which digital content in the form of text, images or 3D models is added, Figure 1. This additional information has different purposes and can be customized according to the needs or specifics of the industry.
Most advanced AR devices are based on SLAM (*Simultaneous Localization and Mapping*) technology. This technology allows the device to gain a dynamic understanding of the user immediate environment, so that digital elements can be placed in the environment or even generated by the environment in ways that make sense to the observer, Figure 2.Tracking allows the application to understand the position and orientation of the object in space. This can allow more powerful applications to run in more dynamic environments, but it is also the basis for some new user interfaces.While object and image recognition allows an app to present information based on the environment, spatial AR allows users to place digital elements into an AR view of the environment. They may include models, notes, or other types of annotations that remain "anchored" to that position in space for their future reference, and often for other users as well [6,7].



Figure 1. View of digital content on the tablet screen in combination with the real world



Figure 2. Overlays of the digital model with the physical model

2. Physical World Virtualization Technologies

So far, several technologies have been developed that combine the digital and physical worlds in different ways. Each of these technologies uses different methods to create the best user experience in merging the digital and physical worlds [8]. There are four basic technologies that involve the digitization and virtualization of the physical world and they are described below. Each of these technologies offers unique ways of interacting with digital content, adapted to different contexts and applications [9].

2.1. Virtual reality (VR)

VR creates a completely digital environment, separating users from the real world [8–10]. There is no overlap with the environment, but the display is completely digital. Users typically wear virtual reality glasses (such as the *Oculus Quest* and *HTC Vive*) that block out the physical world and replace it with a computer-generated one. The ideal solution for simulations, training and virtual experiences where no real-world context is required. Users interact within the virtual environment, often using motion controllers or hand tracking, which simulate actions in the virtual world.

2.2. Augmented reality (AR)

AR overlays digital information onto the real world, thereby enriching the physical environment with digital content [5–13]. Users can access AR through smartphones, tablets, or AR glasses (such as *Microsoft HoloLens* or *Google Glass*). It is used in smart maintenance, navigation applications, interactive maps, etc. Users see and interact with the real world and enhanced digital elements that are consistent with the physical space.

2.3. Mixed reality (MR)

MR combines elements of both VR and AR, allowing digital and real-world objects to interact in real time [11]. MR glasses (such as *HoloLens 2*) allow users to interact with digital objects as if they were part of the physical world, using advanced sensors and spatial awareness. It is used in collaborative environments, industrial training, medical imaging and architectural design. Users can interact with digital and physical objects that react to each other, enabling more sophisticated applications than AR. The basic prerequisite and difference in relation to AR is the existence of sensors and feedback between digital and real content.

2.4. Extended reality (XR)

XR is an parent term for all immersive technologies, including VR, AR and MR. XR encompasses any technology that combines the digital and physical worlds, and is often applied when talking about the broadest spectrum of digital-physical world integration [12]. Used in a variety of industries, XR describes a range of experiences from fully immersive VR to partially enhanced AR. Interaction depends on the specific technology within XR – it can range from simple overlays in AR to fully immersive VR experiences with the use of 3D touch devices (*Haptic Devices*).

3. Purpose of AR in Production and Industry

In production and industry, AR can be used for a variety of purposes. Below are the areas of application of AR within production and industrial environments.

3.1. Improving the training and skills of employees

AR offers a unique opportunity to revolutionize employees training and skill development in Industry 4.0. By providing interactive and real-time guidance, AR can significantly reduce the learning curve for new hires. Workers can overlay digital instructions, diagrams and simulations with machines at their workplace, allowing them to learn complex tasks more effectively, Figure 3.



Figure 3. Workplace learning with AR applications

3.2. Creation of assembly instructions

AR aids the assembly process in manufacturing by overlaying digital instructions directly onto real-world parts, guiding workers step-by-step. This minimizes errors, as employees can visually follow each stage of assembly with real-time instructions and animations. AR tools can also highlight critical components or areas where precision is key, ensuring accuracy and quality. In addition, AR can display 3D models, making complex parts easier to understand and reducing training time for new assembly workers. Overall, AR increases efficiency, improves quality and enables faster learning curves in the product assembly process, Figure 4.



Figure 4. Interactive assembly instructions that recognize the components

3.3. Identification of parts and equipment

AR improves parts recognition in manufacturing by identifying components in real time and displaying relevant information on the screen, Figure 5. Workers

can quickly scan parts with AR devices, which automatically recognize them and display key details such as specifications, part numbers and compatibility. This simplified identification process reduces the possibility of using faulty parts and speeds up assembly and maintenance. In addition, AR provides instant access to spare parts lists, allowing workers to view available inventory, order replacements or find suitable alternatives without leaving their workstation. This improves efficiency and reduces downtime by ensuring the right parts are readily available.



Figure 5. AR application for parts identification

3.4. Enabling remote collaboration - Virtual assistant

AR enables remote collaboration among teams, regardless of geographic location. Through AR-enabled devices, employees can share their views in real time, record objects, and communicate with colleagues, experts, or supervisors, Figure 6.

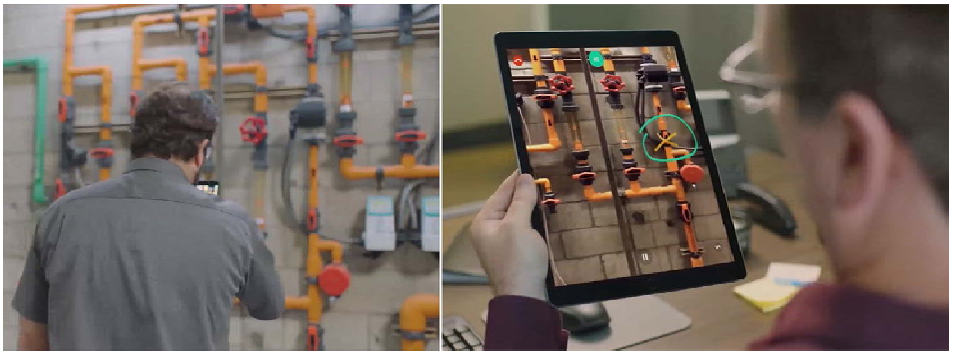


Figure 6.Remote collaboration and expert assistance

Through AR-enabled devices, technicians can receive real-time instructions from experts located in another location. Experts can remotely diagnose problems, provide step-by-step instructions, and even suggest virtual tools within the technician field of view. This capability reduces the need for on-site visits, speeds up maintenance processes, and ensures efficient troubleshooting.

3.5. Improving quality control and inspection

In Industry 4.0, maintaining high quality standards is crucial. AR can improve quality control and inspection processes by overlaying digital information onto physical objects, Figure 7.

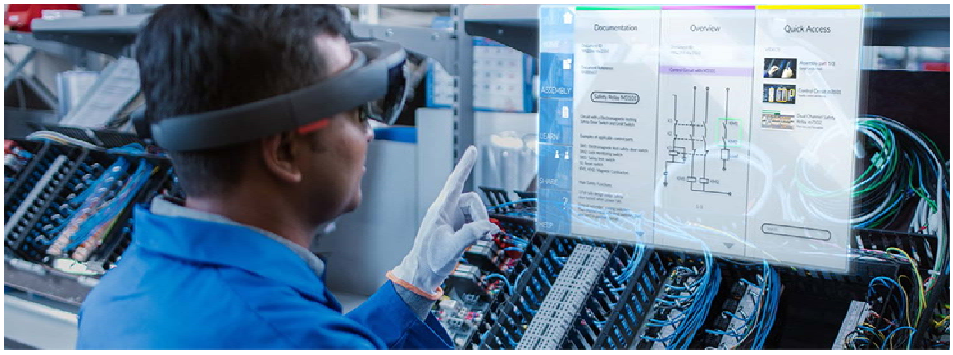


Figure 7. AR procedure for quality control

AR can highlight defects and irregularities in the finished product that might have been missed by the eye, or provide step-by-step inspection instructions and compare real-time data to predefined standards. This technology ensures consistency, accuracy and reduces human error, resulting in improved product quality and customer satisfaction.

3.6. Improving product design and prototyping

AR can revolutionize the product design and prototyping phase in Industry 4.0/5.0. Designers can visualize and manipulate virtual 3D models in realistic environments, allowing them to assess the feasibility, ergonomics and aesthetics of their designs, Figure 8.

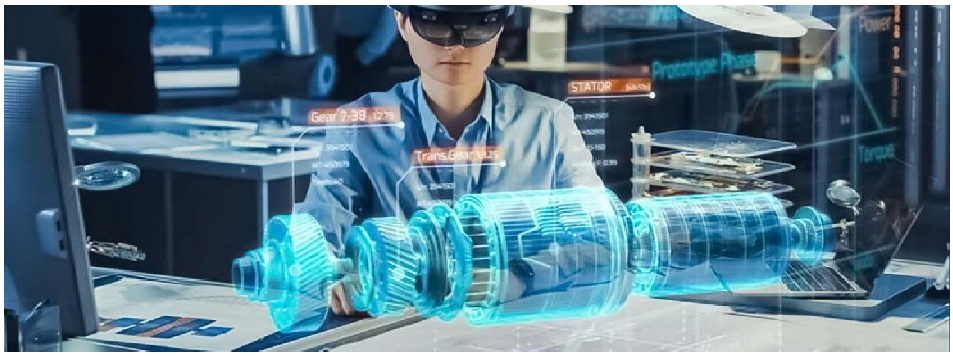


Figure 8. Visualization of the designed part in actual dimensions

AR also enables rapid prototyping, where virtual prototypes can be tested and modified in real time, reducing time to market and development costs. This technology encourages innovation, creativity and accelerates the design iteration process.

3.7. Increasing operator safety

AR can contribute to improving operator safety in manufacturing environments. By overlaying safety instructions, hazard warnings and real-time data on potential risks, AR can help workers navigate their environment more safely. For example, AR can highlight hazardous areas or provide guidance on the proper handling of hazardous materials, Figure 9. This technology promotes a safer work environment, reduces accidents, and reduces the risk of injury.



Figure 9.On-site warning in anindustrial environment

3.8. JIT manufacturing support

Just In Time (JIT) manufacturing is a key principle in Industry 4.0/5.0, aiming to minimize inventory and optimize production efficiency. AR can contribute to JIT manufacturing by providing real-time information on inventory levels, production schedules, and supply chain data. Workers can access this information through AR devices, ensuring they have the right materials at the right time, reducing waste and improving overall production efficiency, Figure 10.

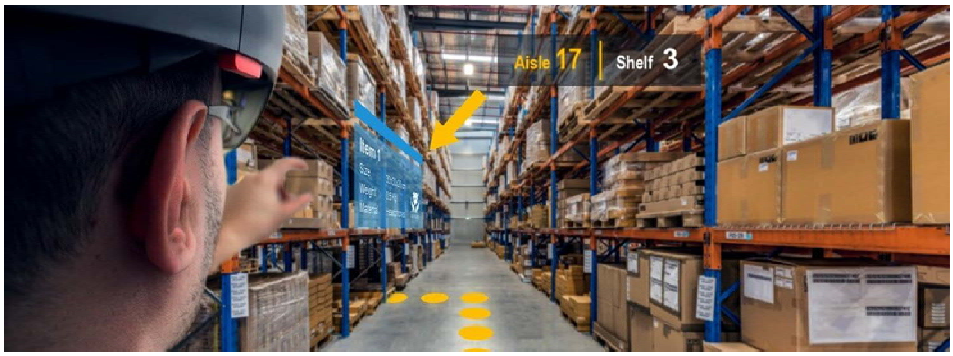


Figure 10.Real-time inventory status

4. Equipment for AR Systems

AR devices usually consist of AR glasses or a transparent screen through which the user looks while displaying applications, a transparent screen onto which the application is projected, or an opaque screen that displays live video content of the user environment supplemented with digital elements [11,12]. This last system, called „passthrough“ is the most common because smartphones and tablets are still the most common AR devices. Passage refers to a built-in camera that transmits a video image of the real world to the device screen.
In addition to the basic hardware requirements of a camera and a screen, more complex AR applications also require sensors for distance detection such as *Time of Flight* – TOF(for *Android* devices) and *Laser Detection and Ranging* – LIDAR (for *iPhone* devices), a gyroscope, and an accelerometer. Also, for remote support functionalities, in real time, an internet connection is necessary [13].
We can state that ready-made mobile phones of the latest generation have all these elements and that there is no obstacle for the mass adoption of these technologies. The quality of these technologies and sensors affect the recognition process in AR applications as follows:

- ***Camera*** plays a significant role in the accuracy and reliability of object recognition in AR applications. Higher-resolution cameras with better image sensors can capture more detailed and clearer images, which can improve object detection and target tracking. Cameras with features such as autofocus, optical image stabilization, and low-light capabilities can also improve the overall AR experience, providing better image quality in a variety of lighting conditions.
- ***Sensors*** used in AR applications are divided into gyroscopes, accelerometers and magnetometers for tracking the orientation and movement of the device. These sensors help determine the position and alignment of virtual objects relative to their real-world environment. The accuracy and responsiveness of these sensors can affect the stability and accuracy of object tracking in AR. Higher quality sensors can provide more reliable data, resulting in smoother and more accurate AR experiences.

- ***Operating system*** of the device may affect the performance and compatibility of AR applications. Different OS versions may have different levels of support for AR functions and API (*Application Programming Interface*) i.e. functionality of the user system. For example, Apple OS has *ARKit*, a framework that provides advanced AR capabilities, while Android has *ARCore*, a similar framework. Availability and functionality of these frameworks may vary depending on OS version and device compatibility. It is important to consider the specific requirements and limitations of the AR framework being used and to ensure compatibility with the OS of the target devices.

For the best AR experience, generally it is recommended to use devices with top quality cameras, reliable sensors, and the latest operating systems.

5. Application of Unity And PTC Vuforia Software Packages in AR

In the domain of AR for industrial applications, the company PTC has imposed itself with its Vuforia software. PTC is known for its Creo (*CAD/CAM*) and OnShape (*Cloud CAD*) software. Vuforia has several subvariants, from a stand-alone version called Vuforia Studio, which is a commercial solution intended for large businesses, to a free version. This is, in fact, an upgrade to the Unity environment, which is intended for creating 2D and 3D computer games and virtual worlds.

5.1. Unity development platform

Unity Engine is a powerful and versatile multi-platform game engine widely used for developing interactive 2D, 3D, VR and AR applications [14]. Unity provides an intuitive development environment with a wide set of tools, including a visual editor, a robust environment for physics and kinematic simulations, and support for the C# programming language. When integrated with the Vuforia Engine, Unity extends its AR capabilities, allowing developers to create applications that recognize and interact with real-world objects, Figure 11.

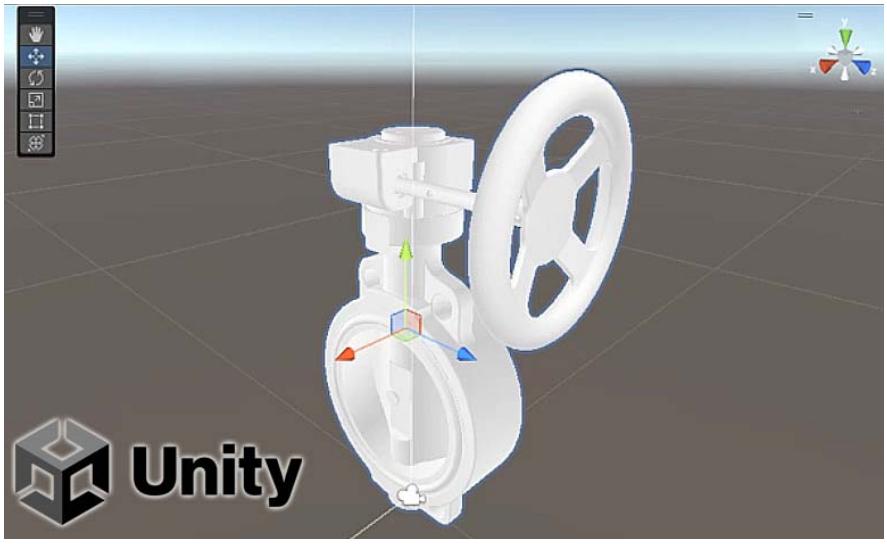


Figure 11. Development of the Unity AR application solution for valve recognition

The Unity environment enables the development of an AR application software solution that can be used in the recognition of machine components. This solution can be adapted to different devices and operating systems. One of the main features of Unity is the development of projects for different platforms. Projects created in this environment can be executed on a total of 27 different platforms [14].

5.2. Vuforia software package

PTC Vuforia is an advanced AR platform that uses a camera to identify and track images, objects and spatial features [15]. Developers can leverage Unity

rendering and scene management tools along with Vuforia recognition and tracking capabilities, enabling the precise overlay of virtual elements onto physical objects in applications such as industrial model recognition and user guidance. Vuforia is a software platform that allows developers to create AR applications for mobile devices and AR glasses. Figure 12 shows the application of AR technology in the recognition of machine components of valves. The ultimate goal is easier identification of parts, assemblies and products in large factories and production facilities. In this way, easier maintenance of machines, devices and equipment is ensured, as well as more efficient replacement of parts.



Figure 12. Application of the Vuforia AR application in the recognition of machine components

Vuforia supports tools for creating and managing different types of AR content on different platforms (*Android, iOS* and *Microsoft*). During virtualization, several different technologies are used for space recognition and positioning of virtual content in the real environment. These technologies include: positioning using 2D graphics – *Image Targets*, positioning using barcodes and QR codes – *Barcode Scanner*, positioning using specially designed graphic targets – *VuMarks*, positioning using graphic targets in the shape of cylinders – *Cylinder Targets*, positioning using graphic targets in the shape of a box - Multi-Targets, positioning using 3D model detection - Model Targets, positioning using plane detection using the phone distance sensor – *Ground Plane* and positioning using space detection – *Area Targets*.

6. Conclusion

AR is ready to revolutionize the manufacturing sector in Industry 4.0/5.0. It upgrades production processes and practices. Its applications in worker training, manufacturing processes, quality control, remote collaboration and product design are transforming traditional manufacturing practices. Using AR companies can improve productivity, reduce costs, improve product quality and drive innovation. It is already realistic to expect that a solution will be found to connect ERP, MES, SCADA, PLC and AR applications in order to obtain all information in real time directly in the factory on a portable device such as a tablet or phone. Such a solution will contribute to a faster response to changes in technological parameters, preventive and emergency maintenance, connection to the warehouse of spare parts, as well as relevant information about suppliers and delivery dates.

Bringing new engineers and operators into industrial processes with AR applications will lead to faster onboarding as well as a better understanding of the manufacturing process and the equipment that is handled and maintained. A digital twin of the factory in a device that fits in your pocket with complete information about every piece of equipment is the ultimate goal of such solutions.

7. References

[1] Milošević, M. (2024).*Industry 4.0 – Digital technologies in the manufacturing process*, Chapter in the book„INDUSTRY 4.0 – Digital transformation is shaping the future“, pp. 1–20, Robotics Society of BiH, Bihać,
Academy of Sciences and Arts, Sarajevo.

[2] Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., Ivkovic, M. (2011). *Augmented reality technologies, systems and applications*, Multimedia Tools and Applications, 51, pp. 341–377, Springer, https://doi.org/10.1007/s11042-010-0660-6.

[3] Lukić, D., Milošević, M. (2022).*Integrated CAPP systemsand PDM*, Technical Science Edition – Textbooks, Faculty of Technical Sciences, Novi Sad.

[4] Egger, J., Masood, T. (2020). *Augmented reality in support of intelligent manufacturing – A systematic literature review*, Computers & Industrial Engineering, 140, 106195,https://doi.org/10.1016/j.cie.2019.106195.

[5] Fang, W., Chen, L., Zhang, T., Chen, C., Teng, Z., Wang, L. (2023). *Head-mounted display augmented reality in manufacturing: A systematic review*, Robotics and Computer-Integrated Manufacturing, 83, 102567, https://doi.org/10.1016/j.rcim.2023.102567.

[6] Palmarini, R., Erkoyuncu, J.A., Roy, R., Torabmostaedi, H. (2018). *A systematic review of augmented reality applications in maintenance*, Robotics and Computer-Integrated Manufacturing, 49, pp. 215–228, https://doi.org/10.1016/j.rcim.2017.06.002.
[7] Marino, E., Barbieri, L., Bruno, F., Muzzupappa M. (2024). *Assessing user performance in augmented reality assembly guidance for industry 4.0 operators*, Computers in Industry, 157–158, 104085, https://doi.org/10.1016/j.compind.2024.104085.
[8] Machała, S., Chamier-Gliszczyński, N., Królikowsk, T. (2022). *Application of AR/VR Technology in Industry 4.0*, Procedia Computer Science, 207, 2990–2998, https://doi.org/10.1016/j.procs.2022.09.357.
[9] Eswaran, M., Bahubalendruni Raju, M.V.A. (2022). *Challenges and opportunities on AR/VR technologies for manufacturing systems in the context of industry 4.0: A state of the art review*, Journal of Manufacturing Systems, 65, pp. 260–278, https://doi.org/10.1016/j.jmsy.2022.09.016.
[10] Siedler, C., Glatt, M., Weber, P., Ebert, A., Aurich, J.C. (2021). *Engineering changes in manufacturing systems supported by AR/VR collaboration*, Procedia CIRP, 96, pp. 307–312,https://doi.org/10.1016/j.procir.2021.01.09.
[11] Karlsson, I., Fathi, M., Grahn, G., Björnsson, A., Wallin, E. (2025). *Towards Zero Defect Manufacturing: Computer Vision-Enhanced Mixed Reality for Quality Inspection*, Procedia CIRP, 134, pp. 1059–1064, https://doi.org/10.1016/j.procir.2025.02.245.
[12] Amouzgar, K., Willebrand, J. (2025). *A novel XR-based real-time machine interaction system for Industry 4.0: Usability evaluation in a learning factory*, Journal of Manufacturing Systems, 82, pp. 254–283, https://doi.org/10.1016/j.jmsy.2025.05.019.
[13] Treinen, T., Keshav Kolla, S.S.V. (2024). *Augmented Reality for Quality Inspection, Assembly and Remote Assistance in Manufacturing*, Procedia Computer Science, 232, pp. 533–543, https://doi.org/10.1016/j.procs.2024.01.053.
[14] https://unity.com/products/unity-engine – Accessed July, 2025.
[15] https://www.ptc.com/en/products/vuforia – Accessed July, 2025.