+

UNIVERSITY OF PATRAS

DEPARTMENT OF MECHANICAL ENGINEERING & AERONAUTICS

DIVISION OF DESIGN AND MANUFACTURING

LABORATORY FOR MANUFACTURING SYSTEMS AND AUTOMATION

Introduction to Augmented Reality Technology and its application to product design

LAMPROS ANTONIS
1059736

Supervisor
Professor Dimitris MOURTZIS

Diploma thesis submitted at Department of Mechanical Engineering & Aeronautics at University of Patras

PATRAS, October 2024

University of Patras, Department of Mechanical Engineering & Aeronautics

LAMPROS ANTONIS

ΕΙΣΑΓΩΓΗ ΣΤΗΝ ΤΕΧΝΟΛΟΓΙΑ ΤΗΣ ΕΠΑΥΞΗΜΕΝΗΣ ΠΡΑΓΜΑΤΙΚΟΤΗΤΑΣ ΚΑΙ ΣΤΗΝ ΕΦΑΡΜΟΓΗ ΤΗΣ ΣΤΟ ΣΧΕΔΙΑΣΜΟ ΠΡΟΙΟΝΤΩΝ

UNIVERSITY OF PATRAS

DEPARTMENT OF MECHANICAL ENGINEERING & AERONAUTICS

DIVISION OF DESIGN & MANUFACTURING

LABORATORY FOR MANUFACTURING SYSTEMS & AUTOMATION

Η παρούσα σπουδαστική εργασία παρουσιάστηκε

από τον

LAMPROS Antonis

1059736

τον Οκτώβριο 2024

Η έγκριση της σπουδαστικής εργασίας δεν υποδηλοί την αποδοχή των γνωμών του συγγραφέα. Κατά τη συγγραφή τηρήθηκαν οι αρχές της ακαδημαϊκής δεοντολογίας.

ΠΕΡΙΛΗΨΗ

Τα τελευταία χρόνια, η 4η βιομηχανική επανάσταση και η εξέλιξη της τεχνολογίας στους τομείς του την αποτελούν, όπως το Cloud Computing, το Internet of Things και η επαυξημένη πραγματικότητα αρχίζει και επηρεάζει την σχεδιαστική και κατασκευαστική διαδικασία ενός προϊόντος. Με την χρήση αυτών των τεχνολογιών, οι μηχανικοί που εργάζονται στον βιομηχανικό τομέα προσπαθούν να βελτιστοποιήσουν την παραγωγική διαδικασία, να ελαχιστοποιήσουν τα σφάλματα κατά την διαδικασία της κατασκευής και να μειώσουν το κόστος σχεδιασμού και κατασκευής του προϊόντος. Όσον αφορά το σχεδιασμό του προϊόντος, μέχρι τώρα χρησιμοποιούνται κυρίως οι συμβατικές μέθοδοι σχεδιασμού με την χρήση προγραμμάτων CAD στον ηλεκτρονικό υπολογιστή. Με την αξιοποίηση της τεχνολογίας της επαυξημένης πραγματικότητας στο σχεδιασμό του προϊόντος, οι μηχανικοί στοχέυουν στην καλύτερη οπτικοποίηση του σχεδίου του προϊόντος και κατά συνέπεια καλύτερη αξιολόγηση της σχεδιαστικής διαδικασίας. Επίσης, η επαυξημένη πραγματικότητα προσφέρει την δυνατότητα για καλύτερη συνεργασία μεταξύ της σχεδιαστικής ομάδας.

Σε αυτή τη σπουδαστική εργασία θα γίνει η περιγραφή της της επαυξημένης πραγματικότητας και θα παρουσιαστεί μια πρόταση εφαρμογής της τεχνολογίας αυτής στο σχεδιασμού ενός προιόντος. Το προτεινόμενο framework βασίζεται στην ανάπτυξη μιας εφαρμογής επαυξημένης πραγματικότητας για έξυπνες συσκευές.

Λέξεις Κλειδιά:

Industry 4.0, Collaborative Design, Extended Reality, Cloud Technologies

ABSTRACT

In recent years, the 4th industrial revolution and the evolution of technology in its fields, such as Cloud Computing, the Internet of Things and Augmented Reality are starting to affect the design and manufacturing process of a product. By using these technologies, engineers working in the industrial sector try to optimize the production process, minimize errors during the manufacturing process and reduce the cost of designing and manufacturing the product. As far as the design of the product is concerned, until now the conventional design methods using CAD programs on the computer are mainly used. By leveraging augmented reality technology in product design, engineers aim to better visualize the product design and consequently better evaluate the design process. Also, augmented reality offers the possibility for better collaboration between the design team.

In this study work, the description of the augmented reality will be made and a proposal for the application of this technology in the design of a product will be presented. The proposed framework is based on the development of an augmented reality application for smart devices.

Keywords:

Industry 4.0, Collaborative Design, Extended Reality, Cloud Technologies

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
AR	Augmented Reality
CAD	Computer Aided Design
CAVE	Computer Aided Virtual Environment
HMD	Head Mounted Display
IDE	Integrated Development Environment
IoT	Internet of Things
STL	Standard Tessellation Language
VR	Virtual Reality
DAQ	Data Acquisition
BLOB	Binary Large Object
ICT	Information and Communications Technology
IAR	Industrial Augmented Reality

CONTENTS

CHAPTER 1
INTRODUCTION

1.1. INTRODUCTION

Collaborative product design has become an essential tool in the field of product design and production, with the goal of minimizing the time and expense involved in developing new products. The main goal of this cooperative project is to make it possible for engineers to collaborate, improving communication and, eventually, product quality [16].

The rapidly developing Augmented Reality (AR) technology offers a promising way to improve and make possible collaborative product design [17]. AR enables users to easily incorporate virtual things into their actual, three-dimensional settings, drastically transforming how the manufacturing process is conceived and carried performed. Virtual models can effectively replace the traditional need for physical prototypes thanks to augmented reality, giving engineers an in-depth understanding of the design process and the final product.

In addition to enhancing and expediting product design processes, augmented reality (AR) technology has a substantial impact on other processes as well, including assembly, quality control, maintenance, repair, and training. Though its potential in product design has been acknowledged, augmented reality is still evolving quickly.

This framework provides a look into the potential for collaborative augmented reality product design by including key features for model visualization and interaction within the AR environment and providing a simple user communication with a cloud database.

1.2. REVIEW METHODOLOGY

The foundation of this review is a thorough analysis of academic, peer-reviewed publications that address the incorporation of product design into manufacturing systems, with a focus on the application of CAD, AR, and VR technologies. A thorough search was carried out using Google Scholar and Scopus, two of the most important scientific databases, to find the pertinent literature. These databases were chosen because they cover a wide range of academic publications. Elsevier provides an extensive abstract and citation database through Scopus, and Google Scholar offers a comprehensive search engine for scholarly literature in a variety of subjects.

Scopus was used for the statistical data extraction process. This database's ability to offer thorough citation analysis made it very useful for identifying important trends and seminal works in the field of study. Citation counts, publication years, and the dispersion of research among journals and conferences were among the data that were taken out of Scopus [17].

The search query is formulated as follows:

(manufacturing) AND (systems) AND (product) AND (design)

The query returned 23107 publications. However, in order to limit the search results, the following keywords/domains have been applied:

- Industry 4.0
- CAD
- Augmented Reality
- Virtual Reality

The total number of documents for each domain is presented in Table 1 and illustrated in Figure 1.

Table 1 Number of publications. Adopted from Scopus, Google Scholar, and Elsevier

Keywords	Total number of publications	Publications 2013-2022
Manufacturing systems, product design, industry 4.0	512	511
Manufacturing systems, product design, CAD	2,966	698
Manufacturing systems, product design, Augmented Reality	116	85
Manufacturing systems, product design, Virtual Reality	588	195

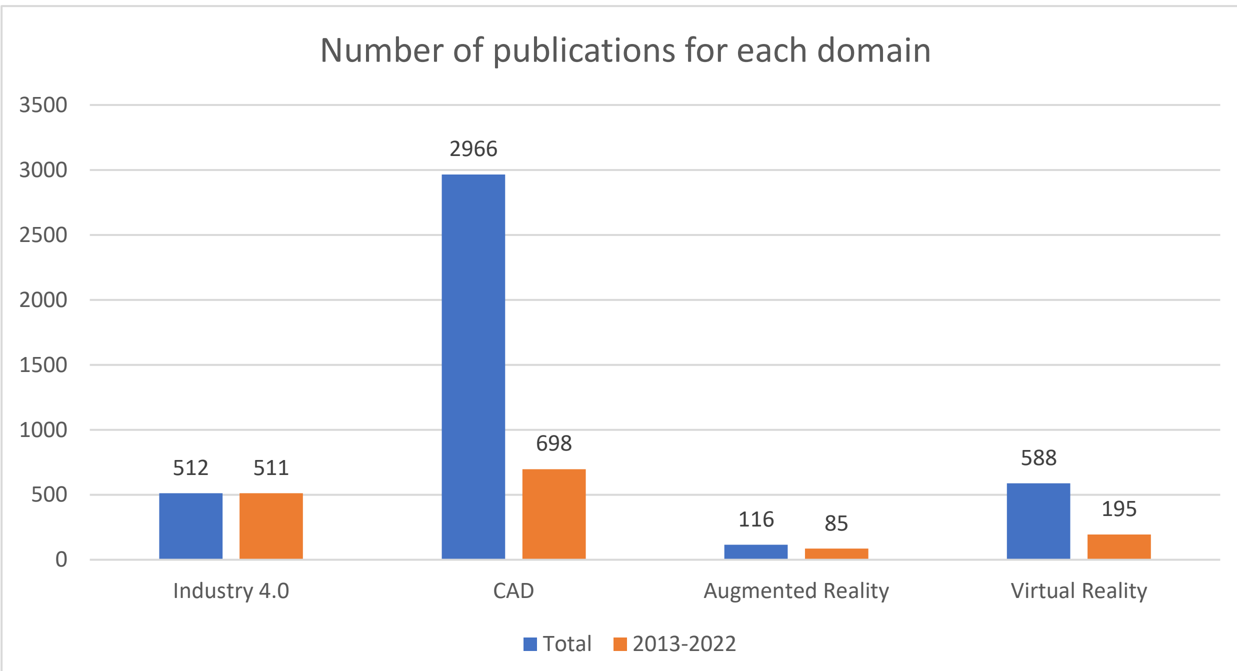

Figure 1 Number of publications per domain. Adopted from Scopus, Google Scholar, and Elsevier

CHAPTER 2
LITERATURE REVIEW

2.1. 4th Industrial Revolution

Industry 4.0, also known as the fourth industrial revolution, is defined as a new degree of organization and control over the whole value chain of a product's life cycle, with a focus on the increasingly customized needs of the consumer [1].

The Industry 4.0 concept encourages the interconnection of physical objects like sensors, gadgets, and business assets with one another as well as with the Internet [1].

Industry 4.0 is described as an emerging structure by the German Federal Government as one in which production and business processes are coordinated and manufacturing and logistics systems , known as Cyber Physical Production Systems (CPPS), heavily utilize the world's available information and communications network [1]. Internet of Things (IoT), Industrial Internet of Things (IIoT), cloud-based manufacturing, and smart manufacturing are the four key forces behind Industry 4.0, which aid in turning the manufacturing process into a fully digital and intelligent one [1].

In the following Figure, the historical development of the industrial revolution is presented.

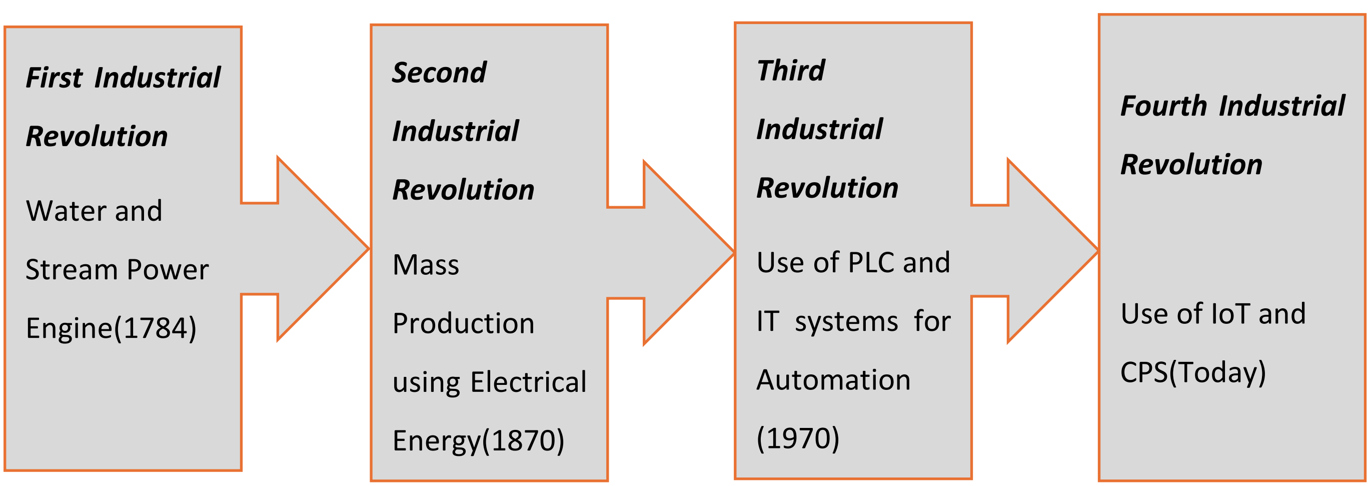

Figure 2: Four Industrial Revolutions. Adopted from [Vaidya, S., Ambad, P., & Bhosle, S. (2018). Industry 4.0–a glimpse. Procedia manufacturing, 20, 233-238.].

The growth of cyber technology in relation to digital ecosystems in the industrial value chain led to the formation of Industry 4.0. Although it was developed in Germany, the idea behind Industry 4.0 has a lot in common with the growth of other European nations where terms like Smart Factories, Smart Industry, Advanced Manufacturing, or Industrial Internet of Things (IIoT) have become popular [2]. Industry 4.0 is the fourth industrial revolution, and it applied the CPS philosophy, the internet, smart systems, and future-oriented technology while promoting frameworks for human-machine interaction (HMI) [2].

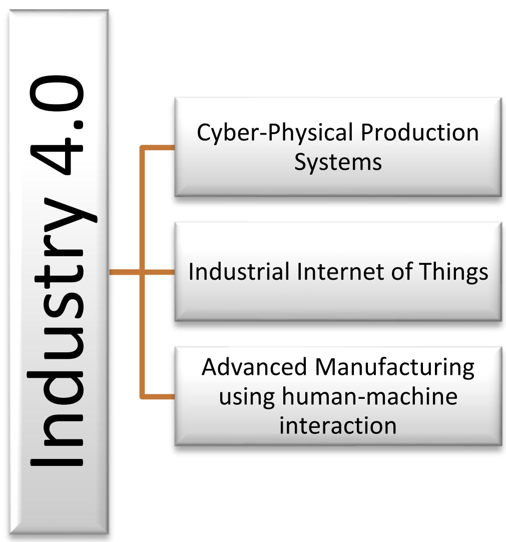

Figure 3: The key forces behind Industry 4.0. Adopted from [Vaidya, S., Ambad, P., & Bhosle, S. (2018). Industry 4.0–a glimpse. Procedia manufacturing, 20, 233-238.].

The nine main technology advances on which the 4th industrial revolution is based are shown in the next Figure.

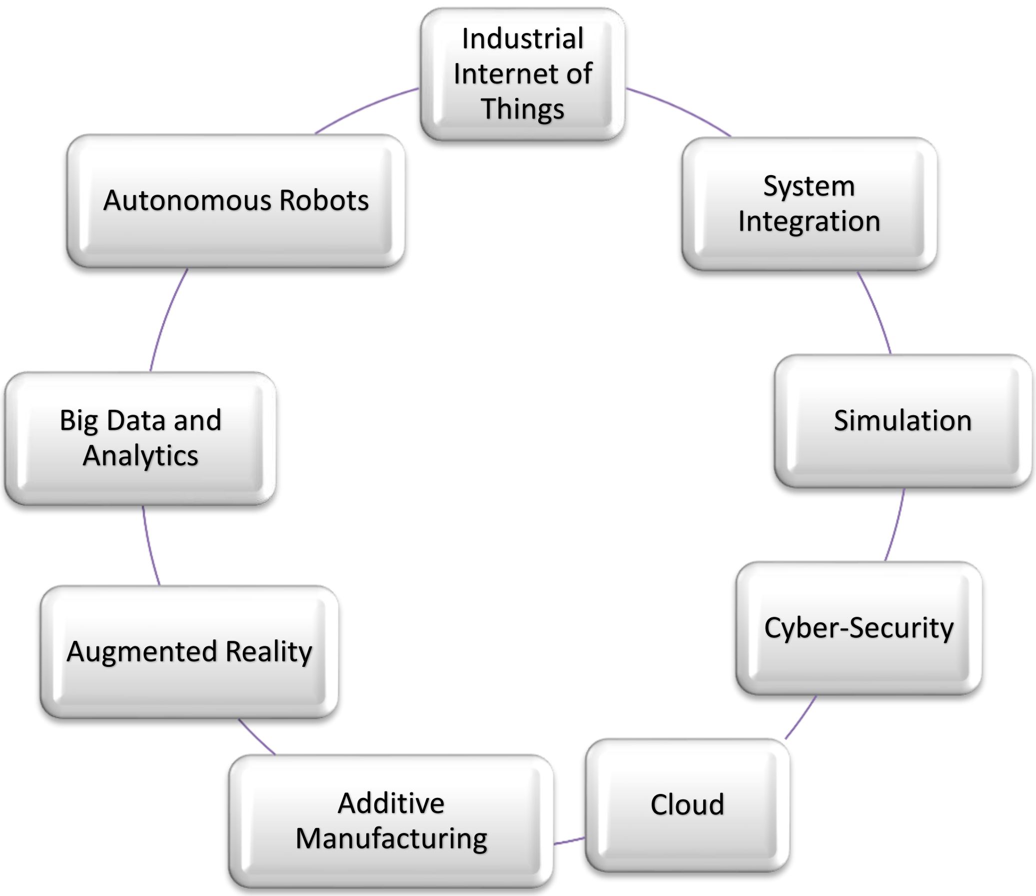

Figure 4: Pillars of the fourth industrial revolution. Adopted from [Palka, D., & Ciukaj, J. (2019). Prospects for development movement in the industry concept 4.0. Multidisciplinary Aspects of Production Engineering, 2(1), 315-326.].

Autonomous Robots

Robots that operate autonomously are typically thought of as systems that integrate perception and action in a changing environment. Robots that can operate autonomously are those that can carry out complex tasks or highly specific external controls by themselves. Robots have been used for a long time by manufacturers across many industries to complete difficult tasks. The capability to make decisions with little human intervention is crucial [2].

Simulation

In the virtual environment, the operator can experiment with and optimize machine settings for the upcoming product via simulation. As a result, the machine set-up time is shortened, and its quality is increased thanks to the earlier physical conversion [2]. By creating a virtual proof of concept before creating a real prototype, simulation can save time and costs. A variety of technological tools and methods are included in simulation that are required for the effective implementation of digital manufacturing [2].

System Integration

By integrating their information and communication technology (ICT) systems, processes, and data streams, value network partners who are locally and globally scattered can operate together. End-to-end digital engineering integration takes place throughout the whole value chain and includes digitalization and intelligent cross-linking at every stage of the product life cycle, from the acquisition of raw materials to the use of the product and the end of its useful life. In order to facilitate cross-functional collaboration and create an intelligent manufacturing environment, vertical integration and networked manufacturing systems integrate internal IT systems, business processes, and data flows from product development to manufacturing, logistics, and sales.

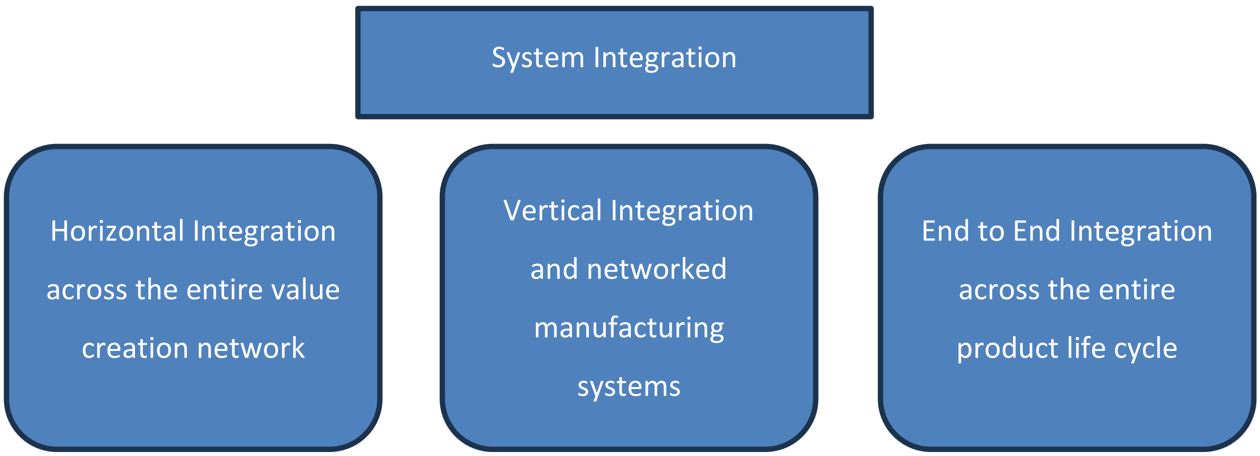

Figure 5: System Integration. Adopted from [Kachiche, S., Gahi, Y., Gharib, J. (2023). An Efficient Framework for the Implementation of Sustainable Industry 4.0. In: Ben Ahmed, M., Boudhir, A.A., Santos, D., Dionisio, R., Benaya, N. (eds) Innovations in Smart Cities Applications Volume 6. SCA 2022. Lecture Notes in Networks and Systems, vol 629. Springer, Cham. https://doi.org/10.1007/978-3-031-26852-6_74]

Industrial Internet of Things

The term "Internet of Things" refers to a global network of uniformly addressed, networked items that communicate via established protocols [1]. IoT is a cutting-edge technology that can connect to systems, real-world items, and services to enable data sharing and object-to-object communication [2]. Manufacturers now integrate IoT into the global supply chain to track the movement of materials and products [2].

Cybersecurity

It is essential to protect critical industrial settings and production lines from cybersecurity attacks as connectivity grows and more advanced communication protocols are used [2]. In considering this, it is essential to have smart identity management, reliable and secure communications, and user and machine access levels. One action that can safeguard ICT systems and their contents is cybersecurity [2].

Cloud

Cloud computing is a concept that allows for on-demand network access from anywhere and at any time. It involves the sharing of configurable computer resource pools, such as servers, services, storage, applications, and networks, which may be immediately provided and published with little administrative time or service provider involvement [2]. Cloud computing has recently emerged as one of the major elements influencing manufacturing, it has the potential to alter the traditional manufacturing industry's business model [2].

Additive manufacturing

Additive manufacturing can be combined with other processes to develop flexible new forms of production, such as a combination of additive manufacturing, injection molding, and humanrobot collaboration. One form of additive manufacturing that can print out a model layer-by-layer from data to solid 3D objects is 3D printing. These additive manufacturing techniques would be used abroad to produce small-volume custom products that have advantages for architecture, like complicated and lightweight designs [2].

Augmented Reality

Virtual objects are used in augmented reality in order to represent a computer-assisted augmentation of human perception. In order to improve the operator's experience of reality, artificial information about the environment and its objects can be placed on the real world utilizing Augmented Reality. Industrial augmented reality (IAR), also known as augmented reality (AR), is a section of technology that provides powerful tools to assist task-bearing operators with assembly tasks, problem-solving, data visualization, indoor positioning, maintenance applications, quality control, or material management [2].

Big Data Analytics

Big data is a collection of technologies that require a new form of integration to find massive hidden values in vast datasets with a wide variety of characteristics. Computing technology can be used to process unstructured data from phone logs, mobile banking transactions, online user generated material like blog posts, tweets, and photographs, as well as online searches, to discover trends and patterns between data sets. Big data analytics is a risk that all types of businesses are making to help them better understand their customers, compete in the market, find insights more quickly, expedite products and services, and maximize earnings [2].

As is now obvious, the 4th Industrial Revolution, has many beneficial impacts on manufacturing industry. No matter how it applies to the product, the procedure, or a factory machine, real-time data access is crucial for manufacturing [2]. Customized labor schedules create everyday operations in real time to reduce the likelihood of mistakes and breakdowns. Because data is instantly available, machines and people can do their tasks more quickly. This could lead to receiving favorable evaluations from the staff and the overall activities have been optimized [2].

Early maintenance is Industry 4.0's next effect. Active maintenance is improved by real-time monitoring of the production system and the gathering of performance data. Large volumes of data, such as machine temperature, vibrations, velocity, overpowering force, condition, and other data, are produced by machines that have sensors installed [2]. It is important to observe the operational status of the machine. Instead of relying on unsecured monitoring by maintenance staff, IoT enables the machine to estimate problems and the maintenance process is launched autonomously [2].

In the next Table are presented the impacts of industry 4.0 on manufacturing industries.

Table 2: Impacts of Industry 4.0. Adopted from [SOROOSHIAN, S., & PANIGRAHI, S. (2020). Impacts of the 4th Industrial Revolution on Industries. Walailak Journal of Science and Technology (WJST), 17(8), 903-915.].

Impacts
Accomplishing high wage economy
Achieving individual customer requirements
Autonomous controlling
Backup system in cloud storage safer and more reliable

Coordinating real time
Creating value opportunities
Demographic of workplace will change
Developing a powerful data security environment
Flexibility
Forming business models evolution
Forming proactive maintenance
Forming smart factory
Gaining financial benefits
Improving energy consumption more efficient
Improving mass customization
Improving safety and reliability in operation
Improving the efficiency of the production processes
Increasing productivity
Increasing revenue growth
Leading to innovation
Mass production becomes highly flexible

Optimizing decision making
Optimizing in procurement process
Precise Risk management
Real time detailed end-to-end product transparency
Reducing costs
Resources become more productivity and efficient
Value chains optimized
Work-life-balance

2.2. Augmented Reality

As previously mentioned, one of the technologies of Industry 4.0 is Augmented Reality (AR). A real-time direct or indirect representation of a physical, real-world environment that has been improved by the addition of virtual, computer-generated information is known as augmented reality (AR) [4]. With AR, a real-world environment can be "augmented" with computer-generated elements or objects rather than being completely replaced by a virtual one.

The augmented reality technology for the proposed framework is based on computer vision methods. More specifically, the same viewpoint from which tracking cameras take pictures of the actual scene is used by computer vision to create 3D virtual objects. A range of computer vision methods, the majority of which are related to video tracking, are used in augmented reality picture registration.

These techniques typically consist of two steps: tracking and reconstructing/recognizing. First, interest points, optical images, and fiducial markers are checked on the camera images [5].

Tracking may use edge detection, feature detection, or other image processing methods to comprehend the camera images. Most tracking techniques used in computer vision can be categorized into two groups: model-based and feature-based. Feature-based techniques are used to determine the relationship between 2D image attributes and their 3D world frame locations [5]. Model-based methods make use of visual representations of the attributes of the tracked objects, such as CAD models or 2D templates based on distinguishable characteristics. In the reconstructing/recognizing stage, a real-world coordinate system is recreated using the information from the first stage [5].

Some methods rely on the presence of fiducial markers or on items with well-known 3D geometry in the surroundings. Others already know the 3D layout of the scene, but the device still needs to remain stationary, and its location must be understood. The Simultaneous Localization and Mapping (SLAM) technique is used to map the relative positions of fiducial markers or 3D models when the entire scene is not known in advance [5].

Developers have access to pre-existing AR libraries like the ARToolKit. You can create augmented reality apps using the computer vision tracking library known as ARToolKit. To determine the camera's position and orientation in respect to physical markers in real-time, it uses video tracking capabilities. Once the actual camera position is known, it is possible to place a virtual camera in the same location and create a 3D computer graphics model to overlay the markers [5].

Marker tracking for augmented reality is a system that locates and follows visual markers in the real environment and superimposes virtual representations over them. The preloaded virtual model is positioned on top of the chosen marker by the AR device's camera after calculating its position and detecting the chosen marker. Augmented reality is employed in sectors including gaming, instruction & training, and industrial design [5].

The relation between the real world coordinates and the device's camera coordinates can be described from the following equation:

$q_i = \mathrm{R} * p_i + \mathrm{T}$

$p_i(x_i, y_i, z_i)^T, i = 1, \dots, n \geq 3$: 3D reference points in the real world

$q_i(x_i{}' y_i{}' z_i{}^i)^T$: The device's camera space coordinates

R: Rotation matrix

T: Translation vector

The position of the camera for the recognition of the images target is shown in the next Figure:

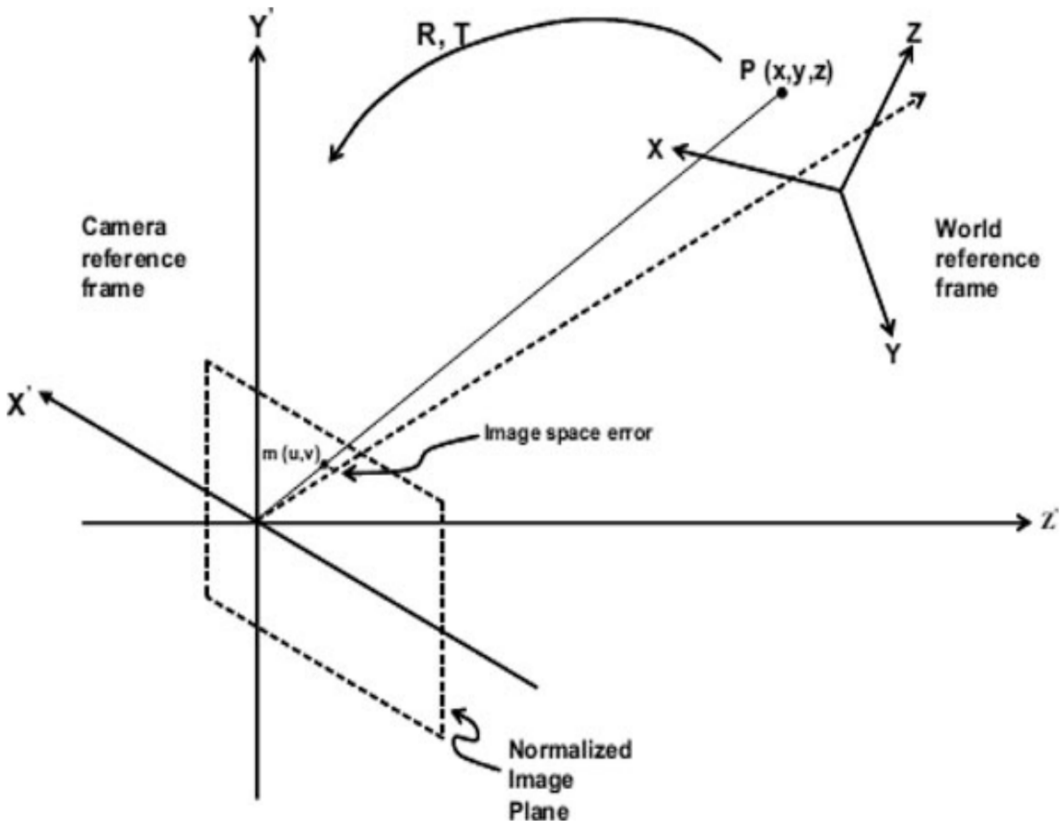

Figure 6: Point constraints for the camera. Adopted from [Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., & Ivkovic, M. (2011). Augmented reality technologies, systems and applications. Multimedia tools and applications, 51(1), 341-377., DOI: 10.1007/s11042-010-0660-6]

2.3. Applications of AR technology in industry

A growing variety of industrial applications based on AR technologies are being developed nowadays. Although most of these applications are still merely prototypes, augmented reality technology is showing to have a lot of potential in a number of different industries, including the automotive, aerospace, and industrial sectors. In the near future, AR systems are anticipated to grow in popularity significantly [6].

The use of AR for assembly is primarily driven by the realization that a large portion of a product's cost is attributable to the assembly process, and that this cost may be significantly decreased if the product is manufactured using a carefully thought-out assembly sequence. AR is therefore being used to try and automate the procedure and increase its effectiveness [6].

Product design/CAD is another well-established sector for AR adoption; in this context, AR is frequently used for product customization to alter/correct the model or engage with its (virtual) 3D components [7].

The major purpose of AR solutions is to help inspectors who are performing on-the-spot equipment inspection or maintenance tasks, such as facility maintenance. It is anticipated that using AR will cut costs by preventing delays and possible errors during maintenance procedures [6].

In the following table are presented the fields of application of augmented reality.

Table 3: Fields of application of augmented reality. Adopted from [Bottani, E., & Vignali, G. (2019). Augmented reality technology in the manufacturing industry: A review of the last decade. IISE Transactions, 51(3), 284-310., DOI: https://doi.org/10.1080/24725854.2018.1493244]

Application field
Assembly
Maintenance
Product design
Safety
Remote assistance
Telerobotics/robotics
Ergonomics
Training/learning
Quality control
Facility inspection or management
Outdoor environment
Picking
Diagnostic
Prototyping

Information
Navigation
2D/3D CAD
Layout planning
Welding
Machining simulation

2.4. AR devices and software

The devices for Augmented Reality are:

- Displays
- Input devices
- Tracking
- Computers

Displays: The three main display formats utilized in augmented reality are spatial displays, portable displays, and head-mounted displays (HMD). An HMD is a display device worn on the head or as part of a helmet that superimposes real and virtual images on the user's field of vision. HMDs can be either video-see-through or optical-see-through and can feature a monocular or binocular display optic. While optical-see-through systems use mirror technology to allow views of the real world to pass through the lens and graphically overlay information to be reflected in the user, video-see-through systems require the user to wear two cameras on his head and the processing of both cameras to provide both the "real part" of the augmented scene and the virtual objects with unmatched resolution [5].

Figure 7: A HMD. Adopted from [Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., & Ivkovic, M. (2011). Augmented reality technologies, systems and applications. Multimedia tools and applications, 51(1), 341-377., DOI: 10.1007/s11042-010-0660-6].

Small computers that include a display the user can carry in their hands are used for handheld displays. They make use of sensors, such as digital compasses and GPS units for their six degrees of freedom tracking sensors, fiducial marker systems, like ARToolKit, and/or computer vision techniques, like SLAM, to overlay images over the real environment [5]. Smartphones are incredibly portable, widely used, and now boast a strong CPU, camera, accelerometer, GPS, and solid-state compass. This makes them a very suitable platform for augmented reality [5].

With the use of video projectors, optical components, holograms, radio frequency tags, and other tracking technologies, spatial augmented reality (SAR) allows users to view graphic data directly on actual things without having to wear or carry a display [5].

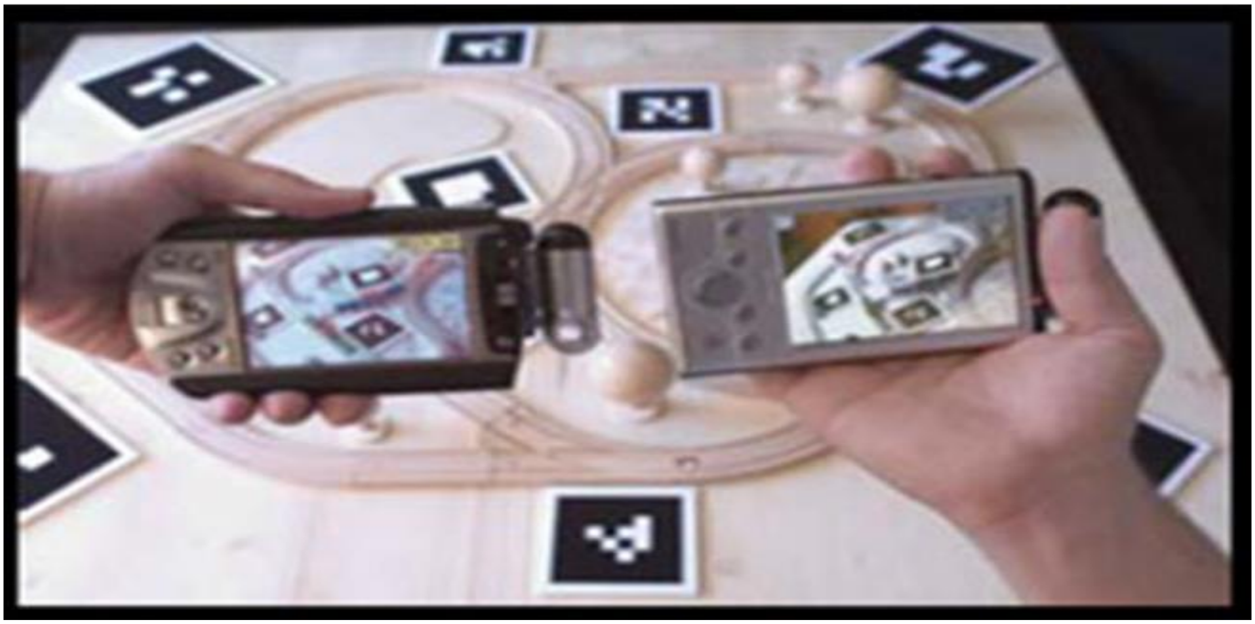

Figure 8: Handheld displays. Adopted from [Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., & Ivkovic, M. (2011). Augmented reality technologies, systems and applications. Multimedia tools and applications, 51(1), 341-377., DOI: 10.1007/s11042-010-0660-6].

Input devices: Gloves, a wireless bracelet, and even the phone itself can be used as an input device [5].

Tracking devices: Examples of tracking equipment include digital cameras and/or other optical sensors, GPS, accelerometers, solid state compasses, wireless sensors, and other tracking devices [5].

Computers: To process camera images for AR systems, a strong CPU and lots of RAM are needed. Currently, mobile computing systems use laptops that are carried around in backpacks, but as smart phone and iPad technology advances, we should expect to see this backpack configuration replaced by a lighter, more upscale-looking device. A typical workstation equipped with a potent graphics card can be used for stationary systems [5].

Various software applications are needed to construct an AR-based application. The 3D models that comprise the AR scenes must first be presented. The 3D CAD program is used to create the 3D models. The most popular 3D CAD programs are [8]:

- SolidWorks
- CATIA
- AutoCAD
- Autodesk Fusion 360

The 3D files created by the aforementioned software typically need to be translated into a different format in order to be supported by the AR application. The most popular programs for converting STL files to COLLADA (.dae) or to.obj,.3ds, or.dxf are [9]:

- Blender
- MeshLab
- Autodesk Meshmixer
- Open 3D Model Viewer

Unity3D is used to create applications for augmented reality and virtual reality. For developers, Unity is a robust cross-platform 3D/2D game engine and Integrated Development Environment (IDE) [10].

For the creation of AR applications, numerous software kits are available. The following are the development platforms that are most frequently used for this [11].

- ARKit
- ARCore
- Vuforia
- Wikitude
- Maxst
- DeepAR

- EasyAR
- ARToolKit
- Xzimg

In the following Figure the differences between the most famous software kits are presented

Table 4: SDK Feauture Comparison Table. Adopted from [Best AR SDK for development for iOS and Android : https://thinkmobiles.com/blog/best-ar-sdk-review/]

	Wikitude	ARKit	ARCore	Vuforia	Max ST	DeepAR	EasyAR	ARToolKit
Maximum distance capture(m)	2.4/5	1.5/5	1.0/3	1.2/3.7	0.5/0.9	0.7/5	0.9/2.7	3/3
Recognition stability of immovable marker	6	9	9	10	7	8	7	8
Recognition stability of movable marker	6	7	6	6	2	7	3	6
Minimum angle recognition	10	30	50	30	50	35	35	10
Minimum visibility for recognition overlapped marker	100%	50%	75%	20%	50%	10%	10%	100%
2D Recognition	YES	YES	YES	YES	YES	YES	YES	YES
3D Recognition	YES	YES	YES	YES	YES	NO	NO	NO
Geo-Location	YES	YES	YES	NO	NO	NO	NO	NO
Cloud Recognition	YES	YES	YES	YES	NO	NO	NO	NO
SLAM	YES	YES	YES	YES	YES	NO	NO	NO

CHAPTER 3
PROPOSED ARCHITECTURE

The framework that has been created focuses on creating an augmented reality application that will be linked to a cloud server. Users of the application will be able to edit and modify 3D CAD designs.

Unity 3D game engine is utilized in the creation of the Graphic User Interface (GUI) and AR application. The Vuforia development kit is chosen for creating 3D and AR scenes. Popular AR application SDK Vuforia is available as an add-on for Unity projects.

The CAD files originate from the design software in a common format, like stl and step. The 3D models must then be translated into a filetype appropriate for the program. Blender, a set of open-source, free 3D computer graphics tools, is utilized for this. The 3D models can then be utilized in a Unity project after being exported from Blender.

A general proposed system architecture is shown in the next Figure.

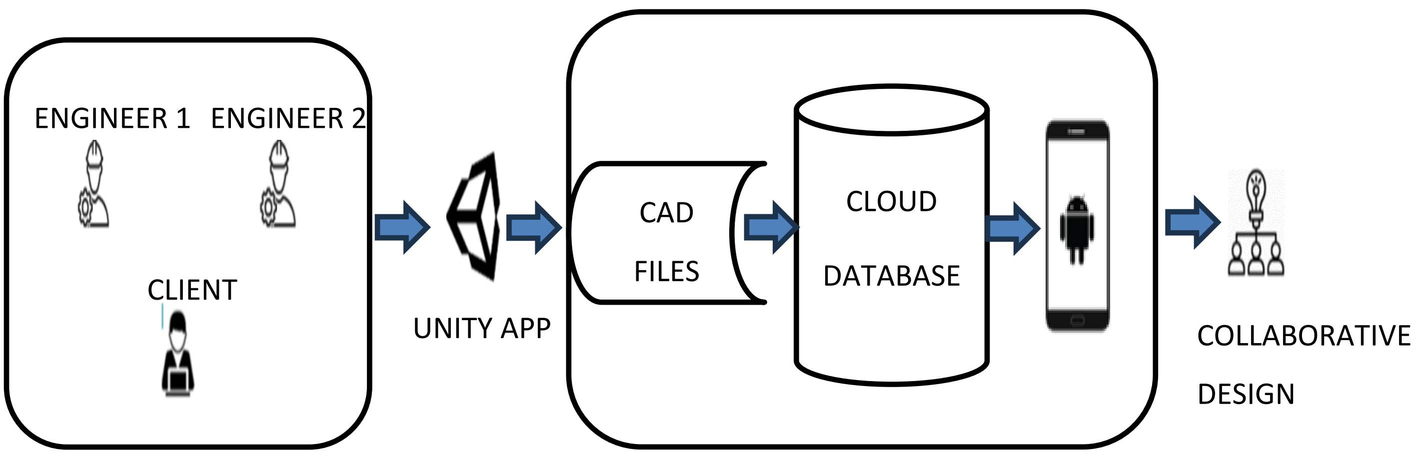

Figure 9: Proposed framework

In the following Figure a more detailed architecture of the proposed framework is presented.

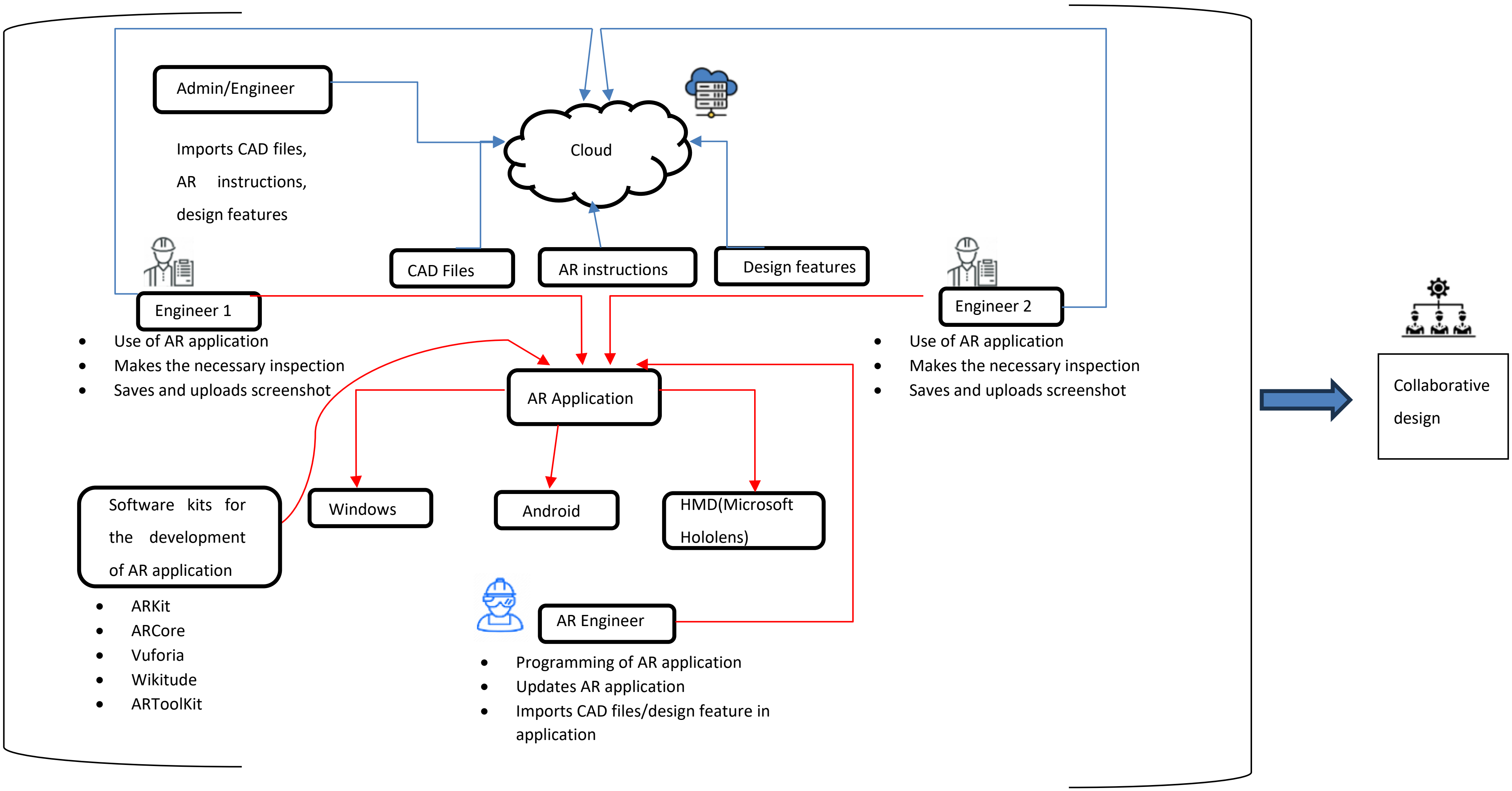

Figure 10: Proposed system architecture

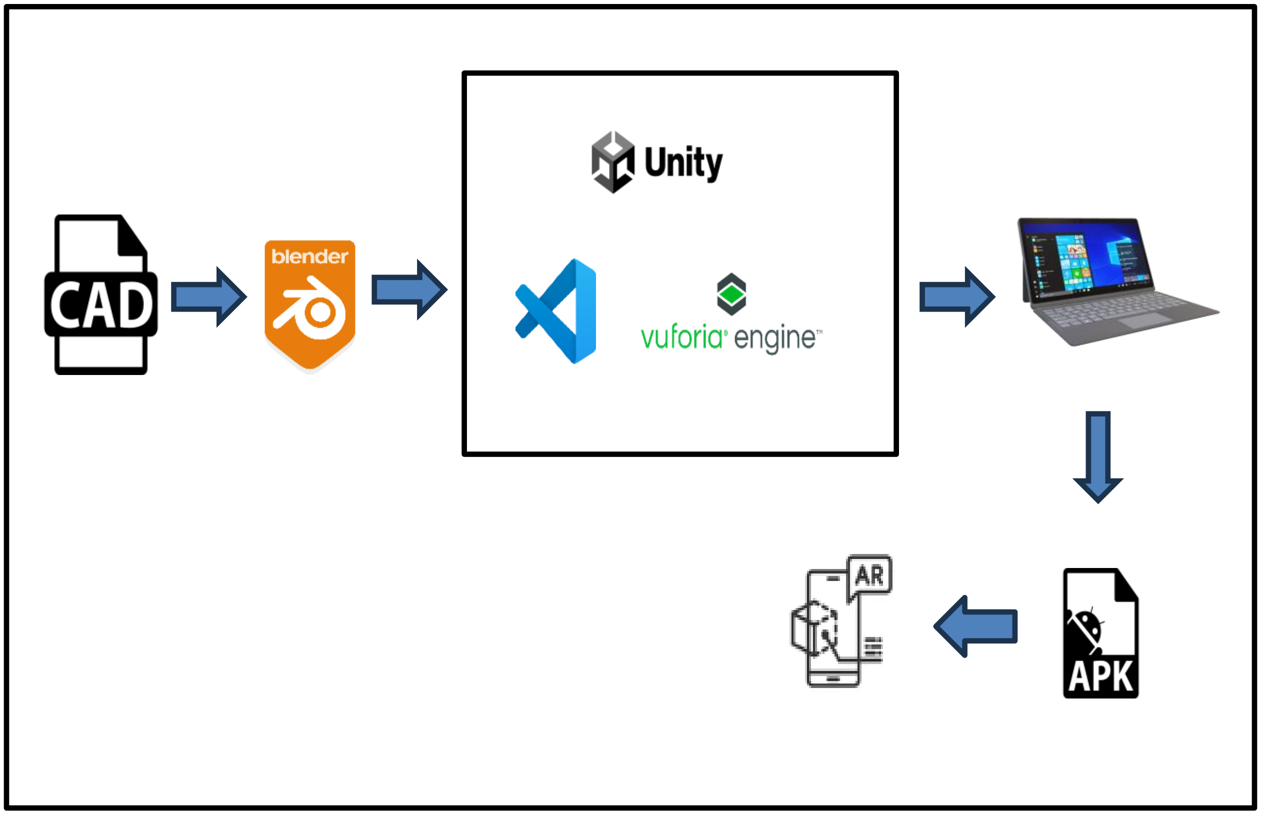

Figure 11: Hardware and software for the development of the proposed framework

CHAPTER 4
DISCUSSION AND OUTLOOK

The proposed framework is based on the development of an AR application. This application is developed for use by android device. Microsoft Visual Studio was used as the main development environment for this project's development. The Unity3D game engine was used to generate the project's main environment within this setting. The Vuforia SDK was also used to build the framework for augmented reality. Vuforia SDK is a powerful software toolset designed specifically for creating augmented reality (AR) apps. The creation of interactive AR applications for a variety of devices and platforms is made possible by its easy connection with popular platforms like Unity3D [12].

Users have the ability through their Android device to visualize a 3D model or parts of an assembly in the physical environment. Users, by aiming the device's camera at a specific image target, can display the 3D model on the device's screen superimposed on the physical world.

Moreover, the application is assisted by a sever which allows the communication and collaboration of users by allowing the upload of files in the database of the server.

The results from the use of such applications in product design are many and important. Some positive results arise from already existing applications that are active in this field and are presented in the table below.

Table 5: Benefits of the use of AR applications in product design. Adopted from [How AR technology can optimize product development : https://dmexco.com/stories/how-ar-technology-can-optimize-product-development/]

Visualization of ongoing projects for customers, partners, and external departments [13]
Sped up development time as a result of improved planning and more thorough examination alternatives [13, 14, 15]

Lower-cost development [13,14,15]
Early phases of development can employ this [13]
Increased safety because of lower risks [13]
Enhanced cooperation through shared access to all necessary information and data in real time [13]
Effective product optimization involves finding and fixing mistakes and weaknesses as soon as possible [13,14,15]
Enhanced design creativity [13]

A revolutionary change in the way teams approach and carry out design processes is being facilitated by the use of Augmented Reality (AR) into collaborative product design. The potential of augmented reality (AR) technology to transform collaborative creative processes is becoming more and more apparent as it develops. The previous table presented some fields in which the use of augmented reality affects and will have a positive effect in the coming years.

The availability of cutting-edge technology and software is necessary for augmented reality to be effective in product development. Continued development is required to lower the cost and increase the accessibility of AR tools.

The resolution, field of vision, and user comfort of current AR devices may be limited. These restrictions should be lifted as technology develops, improving the user experience as a whole.

In addition, ensuring strong data security measures will be essential as augmented reality (AR) is used more and more for critical design projects. Finally, the integration of AR with AI and machine learning has the potential to further improve design capabilities in the immediate future.

CHAPTER 5
CONCLUSION

In this paper, an attempt was made on the subject of collaborative product design using Augmented Reality and a basic AR application was developed that supports the proposed framework. The field of collaborative product design is being drastically transformed thanks to augmented reality (AR). It enables teams to collaborate easily, improving innovation and productivity. Creativity and decision-making are improved by AR's capacity to deliver realistic, real-time interactions with 3D models in shared virtual settings.

Although there are some obstacles to be solved, such as technology requirements, hardware limitations and data security, there are several advantages to using AR in collaborative product design.

As augmented reality (AR) technology develops, its introduction into design processes has the potential to be a significant element that will influence how products are developed in the future.

REFERENCE LIST

1. Vaidya, S., Ambad, P., & Bhosle, S. (2018). Industry 4.0–a glimpse. Procedia manufacturing, 20, 233-238.
2. SOROOSHIAN, S., & PANIGRAHI, S. (2020). Impacts of the 4th Industrial Revolution on Industries. *Walailak Journal of Science and Technology (WJST)*, *17*(8), 903-915.
3. Palka, D., & Ciukaj, J. (2019). Prospects for development movement in the industry concept 4.0. *Multidisciplinary Aspects of Production Engineering*, *2*(1), 315-326.
4. Mourtzis, D. (2020). Simulation in the design and operation of manufacturing systems: state of the art and new trends. International Journal of Production Research, 58(7), 1927-1949., DOI: https://doi.org/10.1080/00207543.2019.1636321
5. Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., & Ivkovic, M. (2011). Augmented reality technologies, systems and applications. Multimedia tools and applications, 51(1), 341-377., DOI: 10.1007/s11042-010-0660-6
6. Bottani, E., & Vignali, G. (2019). Augmented reality technology in the manufacturing industry: A review of the last decade. IISE Transactions, 51(3), 284-310., DOI: https://doi.org/10.1080/24725854.2018.1493244
7. Mourtzis, D. (2020). Simulation in the design and operation of manufacturing systems: state of the art and new trends. International Journal of Production Research, 58(7), 1927-1949., DOI: https://doi.org/10.1080/00207543.2019.1636321
8. Choosing the Best 3D CAD Software: A Comprehensive Guide : https://formlabs.com/blog/cad-software/
9. 6 Best Free STL to DAE Converter Software for Windows: https://listoffreeware.com/free-stl-to-dae-converter-software-windows/
10. Unity Real-Time Development Platform | 3D, 2D VR & AR : https://unity.com/
11. Best AR SDK for development for iOS and Android : https://thinkmobiles.com/blog/best-ar-sdk-review/

12. Vuforia Engine Developer Portal : https://developer.vuforia.com/
13. How AR technology can optimize product development : https://dmexco.com/stories/how-ar-technology-can-optimize-product-development/
14. Extended reality: Virtual, augmented, and mixed: Extended Reality (XR) | Virtual, Augmented, Mixed Reality | Autodesk
15. Wang, J., & Qi, Y. (2022). A multi-user collaborative AR system for industrial applications. *Sensors*, *22*(4), 1319. DOI: https://doi.org/10.3390/s22041319
16. Mourtzis D. (2020). Simulation in the design and operation of manufacturing systems: state of the art and new trends, International Journal of Production Research, 58:7, 1927-1949, DOI: https://doi/org/10.1080/00207543.2019.1636321
17. Mourtzis, D. (2020). Machine Tool 4.0 in the Era of Digital Manufacturing. 17th International Multidisciplinary Modeling & Simulation Multiconference. DOI: https://doi.org/10.46354/i3m.2020.emss.060
18. Kachiche, S., Gahi, Y., Gharib, J. (2023). An Efficient Framework for the Implementation of Sustainable Industry 4.0. In: Ben Ahmed, M., Boudhir, A.A., Santos, D., Dionisio, R., Benaya, N. (eds) Innovations in Smart Cities Applications Volume 6. SCA 2022. Lecture Notes in Networks and Systems, vol 629. Springer, Cham. https://doi.org/10.1007/978-3-031-26852-6_74