Journal of Architecture and Design 8[19]1-13: 40819113
Article

Augmented reality in the educational context for the digitalization of products and mathematical applications

Realidad aumentada en el contexto educativo para la digitalización de productos y aplicaciones matemáticas

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CONAHCYT classification:

Area: Engineering
Field: Engineering
Discipline: Systems engineer
Subdiscipline: Computer Sciences

https://doi.org/10.35429/JAD.2024.8.19.1.13
History of the article:
Received: January 19, 2024
Accepted: December 31, 2024

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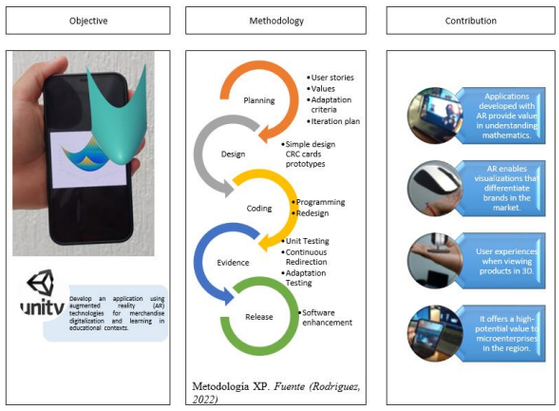
Abstract

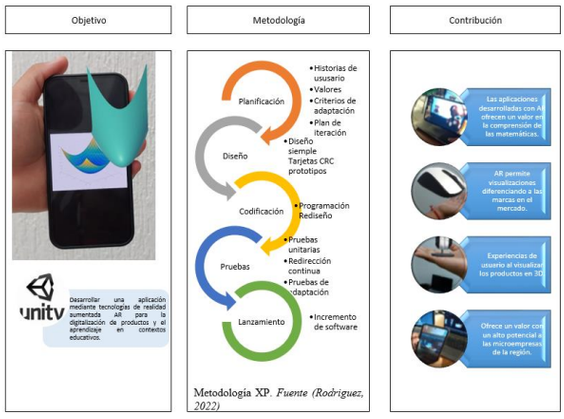
The objective of this project was to develop an application using AR augmented reality technologies for the digitalization of products and learning in educational contexts. The extreme programming (XP) methodology was used for its development which comprises the stages: planning, design, coding, testing, launch. As a result integrating Vuforia into Unity enabled the creation of augmented reality (AR) applications for mobile devices in this project was used the operating system of Android, Tests were carried out to determine how Vuforia works in Unity using Image Targets and 3D Models, an installation manual was developed for beginners to integrate their knowledge, practical problem solving, Interactivity and meaningful learning.



vuforia, Augmented realit

Resumen

El objetivo de este proyecto fue desarrollar una aplicación mediante tecnologías de realidad aumentada AR para la digitalización de productos y el aprendizaje en contextos educativos. Se utilizó la metodología de programación extrema (XP) para su desarrollo que comprende las etapas de: planificación, diseño, codificación, pruebas, lanzamiento. Como resultado integrar Vuforia en Unity permitió la creación de aplicaciones de realidad aumentada (AR) para dispositivos móviles en este proyecto se utilizó el sistema operativo de Android. Se realizaron pruebas para poder determinar cómo es el funcionamiento de Vuforia en Unity mediante Image Targets y Modelos 3D, también se elaboró un manual de instalación enfocado a principiantes con la finalidad de que puedan integrar sus conocimientos, resolución de problemas prácticos, interactividad y aprendizaje significativo.



Unity, vuforia, Realidad aumentada

Citation: Del Carmen-Morales, Yucels Anaí, Del Carmen-Morales, Heidi, Felipe-Redondo, Ana María and Juárez-Castillo, Efrén. [2024]. Augmented reality in the educational context for the digitalization of products and mathematical applications. Journal of Architecture and Design. 8[19]-1-13: e40819113.

Introduction

(De la Horra, 2017) indicates that the pedagogical use of augmented reality (AR) is a tool to obtain two fundamental pillars on which the day-to-day life of the classroom is based: motivation and learning. It is necessary that these new innovative tools meet the fundamental requirements for their use, in this case, in the field of education and training. Some of them are: ease of creation of material for the teacher, ease of use for the student, attractive and user-friendly interface and interdisciplinarity.

Augmented reality is a tool with very special characteristics that give it great possibilities for inclusion in the educational and training sphere. Its versatility, transversality and ease of use make the user feel comfortable during the learning process. Thanks to the development of mobile devices, augmented reality is closer than ever to the user.

The project was developed at the Universidad Tecnológica de la Huasteca Hidalguense because currently, students of the educational programme of Engineering in Software Development and Management, take the subject of mathematics I, where they make use of 3D graphics and multivariable calculation problems, in addition to this they carry out a transversal project for micro-businesses in the region but lack the knowledge to develop a tool that allows them to visualise in augmented reality, which hinders their understanding and application in the digitisation of products and mathematical models.

Given the aforementioned problems, one area of opportunity was the integration of augmented reality in a mobile application for the educational environment so that students can visualise and acquire applied learning.

A tool was developed as an innovative solution, to enhance the applied learning experience, to generate a significant impact by solving specific problems, Unity and Vuforia will be used for the generation of augmented reality (AR) models.

In the commercial environment, the presentation of products online using AR technology brings value to their products or services by generating a positive impact on sales, brand image and competitive position. The objective of this project was to develop an application using AR augmented reality technologies for product digitalisation and learning in educational contexts.

Theoretical foundations

Augmented reality

Augmented Reality, hereafter AR, is a technology that superimposes images, 3D models or other computer-generated information on a real image obtained through a screen. It is a new window through which the world can be seen in an enriched form. Also, 'Augmented reality is about combining the real world with the virtual world through a computer process, enriching the visual experience and improving the quality of communication'.

Levels of augmented reality

Augmented Reality can be classified into levels according to the way it works, parameters, tracking systems and techniques used.

Level 0: hyperlinks in the physical world. The triggers at this level are QR codes that link to websites. A QR code (Quick Response code) is a module for storing information in a dot matrix or two-dimensional barcode. It was created in 1994 by the Japanese company Denso Wave, a subsidiary of Toyota.

Level 1: augmented reality based on reference markers. These are objects used for the observation of imaging systems, which appear in the image to be used as a reference or measurement point. At this level the triggers are markers, figures that when scanned usually result in a 3D model that is superimposed on the real image. The markers need a unique pattern, which will allow the camera to recognise and determine the object(s) to be displayed.

The markers usually consist of a black square with a certain pattern inside it, which allows them to be differentiated from each other.

ISSN: 2531-2162
RENIECYT-CONAHCYT: 1702902

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Level 2: augmented reality without markers. Activators are images, objects or GPS locations. In recent years (since 2009), applications for mobile devices called augmented reality navigators have been developed; these applications use smartphone hardware (GPS, compass and accelerometer) to locate and overlay a layer of information about points of interest in our environment (Figure 4). When the user moves the smartphone around capturing the image of their surroundings, the browser, based on a map of data, displays nearby points of interest (POIs).

Level 3: augmented vision. The purpose of augmented reality incorporated in glasses is to display information available to users without using their hands, also allowing access to the internet through voice commands.

Augmented reality in education

Education is also starting to take advantage of mobile applications (apps) and Augmented Reality (AR). For both teachers and students, AR educational apps can provide highly entertaining and useful learning tools, exploiting the visual component as their main attraction, using animations and videos. For example, AR is of great importance in subjects that require a more practical dimension, such as physics and chemistry. In this way, it is of vital importance that the educational field is driven by technology and one way of impact is to develop an application in an AR environment where teaching for children is more important and attractive than the current violent games, as these create disruption in teaching and do not support any progress for their education and much less for the future of our country.

The educational and technological reality in the classrooms of the different academic levels in our educational system today, comes our educational system today, comes hand in hand with the incorporation of new tools that bring students and teachers tools that bring students closer, in a simple, fun and formative way, to the curricular contents, to curricular content in a simple, fun and educational way. One of the technologies that is currently gaining momentum and importance is is Augmented Reality, which has been gaining ground, especially in higher education in higher education.

AR technology as a teaching resource

AR is a technology that enables a learning-¬-teaching methodology based on these principles: Augmented reality visibly introduces the knowledge that the student has to learn within his or her real environment. The abstraction of the new knowledge is visible and is in the learner's real physical environment. The experience is underpinning the learning.

This new ‘reality of the learning process’ entails a new learning experience as opposed to other resources. In addition, the novelty factor, the emerging technology factor and the ‘reality’ factor can lead to an increase in the students' level of understanding, in the effectiveness of the learning process and in the motivation to learn.

Vocational training and skills development

Vocational training is one of the major areas of application of Augmented Reality, being able to recreate real work situations and improve understanding in practical training activities by superimposing relevant information to allow better monitoring of processes.

In this context, Augmented Reality can offer, for example, the possibility of interacting with industrial machinery on which a layer of data is displayed to provide additional information on its use, thus improving the training of assembly and maintenance technicians and preventing possible errors in its handling.

In the field of vocational training, Augmented Reality can become a tool that facilitates the acquisition of practical learning in virtual training or e-learning processes. The development of Augmented Reality tele-training platforms would allow the possibility of reproducing tailor-made work contexts, with the aim of providing more practical training and solving the shortcomings of online training in this sense, providing access to content that can only be offered by face-to-face training.

Fields of augmented reality

AR has been used to create unique experiences, engage audiences and improve the way media is used.

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The entertainment sector, particularly video games incorporating AR, is expected to remain the largest segment in the B2C (business to consumer) AR software market, reaching EUR 1.65 billion by 2027. Thus, in terms of the use of AR in the entertainment sector, it is worth mentioning:

- Games: AR has revolutionised gaming by providing immersive and interactive experiences that combine the virtual and physical worlds. One of the most representative examples is Harry Potter: Wizards Unite, based on the Harry Potter franchise, developed in 2019 by the creators of Pokémon GO.

- Live events: AR is being used in live events such as concerts, sporting events and theatrical performances to provide unique and immersive experiences for the audience. An example of such experiences is the FIFA+ Stadium Experience associated with live matches at the Qatar 2022 World Cup, which allowed viewers to visualise additional information about players and game metrics.

- Film and TV: AR is being used to create interactive content that allows audiences to interact with their favourite programmes and characters in new ways. For example, the 2021 Super Bowl TV broadcast used a virtual AR stadium to enhance the viewing experience, allowing the game to be viewed from different angles and providing additional statistics and information.

It is possible to learn by playing and through games and with Augmented Reality technology, achieve a better approach to our students, increase motivation, greater interaction and immersion and more meaningful learning.

Augmented Reality as a sales strategy

Business models in companies are undergoing far-reaching changes to the extent that e-commerce is establishing itself as a benchmark, through its business-to-consumer format, it allows entering the digital market in collaboration with vision technologies such as augmented reality.

One factor to be included are the technological tools, in the sales process, adding a differentiator from the competition adds value to the good or service offered to the customer. AR offers the possibility of enriching the multimedia content of the article, interaction with three-dimensional objects and the exploration of a virtual world with smart devices.

Consumer experiences and behaviour

AR has the potential to significantly impact the so-called consumer journey by enhancing user experiences, delivering personalised content and facilitating informed purchasing decisions. Thus, AR enables the creation of immersive and interactive experiences that can enrich the consumer journey at various touch points, from product discovery to post-purchase engagement.

During the pre-purchase stage, consumers become aware of their needs and begin to seek information about possible solutions. As is well known, this stage includes processes such as problem recognition, information search and evaluation of alternatives. In this regard, research on AR often points out how the inclusion of virtual information within the context of consumers can reduce purchase uncertainty. They have shown that embedding branded content in physical contexts relieves consumers of the mental burden of imagining a product. Therefore, virtual content can influence perceptions of ease of use and information consumption.

Compared to traditional media, such as 2D images and text, 3D virtual technologies feature 360-degree rotation, which offers enhanced product/environmental realism, rich imagery and rapid information transfer. Users easily manipulate visual spaces through advanced virtuality features such as zoom and rotation.

From a retail management point of view, AR reduces the extent of stock, as virtual content can replace the need for an assortment that allows for consumer trial.

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In terms of the purchase stage, i.e. the specific moment when the consumer makes the decision to buy a good or service and executes that action, AR ads improve consumers' physiological responses, increase their engagement and facilitate the exchange of social experiences between them (Morejón, 2023).

Shopping experiences and their relationship to augmented reality

In the pandemic, many brands were forced to close their physical spaces and conduct their commercial activity online with the help of tools such as augmented reality.

According to the Mexican Association of Online Sales COVID-19 brought with it an increase in purchases and sales in virtual environments by increasing by 81% in 2020 compared to 2019. Likewise, COVID-19 brought health restrictions, which were implemented by the federal government. This situation reshaped consumer habits, as the implemented social distancing influenced consumers to prioritise online shopping.

A report by the consultancy predicts that the number of augmented reality applications for retail will increase from 12 million in 2019 to almost 3 billion in 2024.

Those actions that use AR as a tool manage to meet 4 basic requirements of advertising effectiveness:

- Interact with the consumer.
- Create personalised content.
- Measure results in real time.
- Impress the consumer and make them remember the advertising.

Enterprise use has dominated the augmented reality conversation for the past few years, the tide is turning. All of the technology companies that can change markets on a global scale are already directly involved in AR, and many are planning more dedicated AR hardware efforts in the next two to three years.

During the pandemic, digital commerce saw tremendous growth. According to AMVO, in the Retail sector alone, e-commerce grew 81% in 2020 compared to 2019, and accounted for 9% of the total retail channel in Mexico.

As shops closed dressing rooms and eliminated product trials, brands implemented technologies such as Augmented Reality (AR) to allow customers to try their products virtually, while helping them make a purchase decision.

Today, consumers are ready for a new way of shopping. In fact, more than 71% of customers are confident that they would shop more frequently if they could use AR tools.

One study found the following:

- 1 in 3 shoppers already use AR
- 71% of consumers would shop more often in a shop if the store offered AR.
- 47% would prefer to use AR both in-store and online
- 40% would be willing to pay more to brands that already offer AR

3D modelling tools

Using object modelling tools and AR applications, teachers and students can create and visualise 3D models and manipulate them: zoom in, zoom out, rotate them, place them in specific locations or explore their physical properties.

Vuforia in Unity

Vuforia Studio is an easy-to-use, web-native tool for creating task- and domain-specific experiences. These experiences provide a holistic view of digital and physical product data, dashboards and prompts in 2D, 3D and augmented reality. Once an experience has been created with Vuforia Studio and published to Experience Service, it can be viewed with the Vuforia View application on a supported device. The Unity editor is a popular and useful authoring platform for creating cutting-edge augmented reality experiences for wearable devices and digital glasses.

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Wikitude

Wikitude is an augmented reality technology tool, created from 2008 and one of the pioneers in exposing a different location-based perspective for augmented reality. In 2012, the company redesigned its offering by launching a development system that employs image recognition, image tracking and geolocation technologies called Wikitude SDK; years later, Wikitude introduced its SLAM technology, which comprises localisation, mapping and also instant tracking of objects without markers.

It allows you to create AR experiences with image recognition, geolocation and markers. Compatible with iOS, Android, Windows and Smart Glasses.

AR.js

Lightweight library for Augmented Reality on the Web, which comes with features such as image tracking, location-based AR and marker tracking. The interesting thing about this library is that it works very well with AFrame which is a library for creating virtual reality experiences on the web.

Methodology

Extreme programming (XP) is a software engineering development methodology formulated by Kent Beck, author of the first book on the subject, Extreme Programming Explained: It is the most prominent of the agile software development processes. Like these, extreme programming differs from traditional methodologies mainly in that it places more emphasis on adaptability than predictability.

Extreme programming can be considered as the adoption of the best development methodologies according to what is intended to be carried out with the project, and applying it dynamically during the software life cycle (Rodriguez, 2022)

Box 1

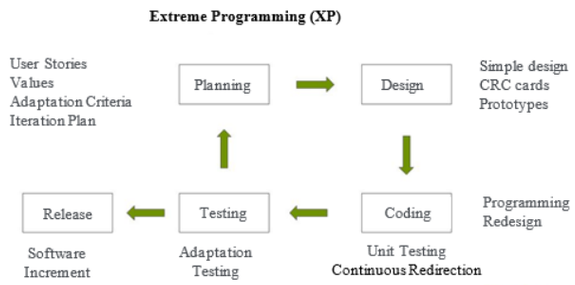

Figure 1
Title: XP Methodology
Source: (Rodriguez, 2022)

Planning

In this phase a comparative table was developed showing applications oriented to create 3D projects using AR technology, within them we analysed the license, the platform on which they work, advantages and disadvantages, minimum requirements: Unity, vuforia, spark AR, Lends Studio, Photoshop, Affinity photo, Blender.

After the analysis it was determined to use Matlab for mathematical applications and graphics, Unity and vuforia to implement 3D models, Lens Studio and Meta Spark Studio for AR interaction in social networks.

User stories were created, as in software development, it is essential to have a clear and structured guide for the integration of tools.

- Description of the process of loading the SDK file into the project.
- Integrate SDK into Unity.
- Image target implementation.
- Upload the 3D models.
- Generate the APK.

The correct configuration and generation of the APK in Unity is essential to ensure that the application can be distributed and installed on Android devices at a given time, complying with the standards and working as expected in the final environment.

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Design

3D graphics design.

Box 2

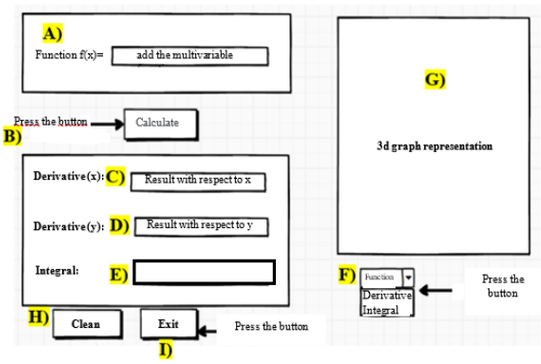

Figure 2
Title: Partial integral and derivative calculator

Source: Own elaboration, 2024

An application for calculating partial derivatives as a function of x, y and 3D graphics were modelled in preparation for SDK integration.

Unity 3D model designs.

Box 3

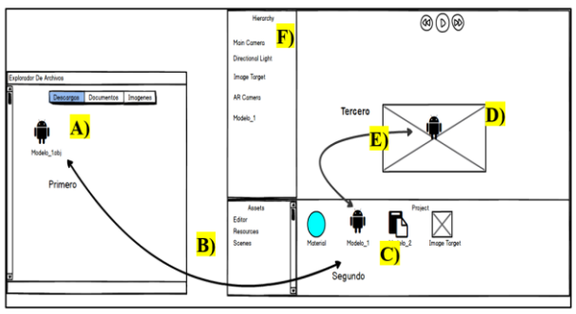

Figure 3
Title: 3D Unity Modelling

Source: Own elaboration, 2024

Workflow:

A. File explorer view, 3D models are found.
B. Drag model from file explorer to unity.
C. Model added to unity.
D. Model added to unity interface.
E. Image target which will be scanned to visualise the 3D model.
F. Application components.

Result display screen

Box 4

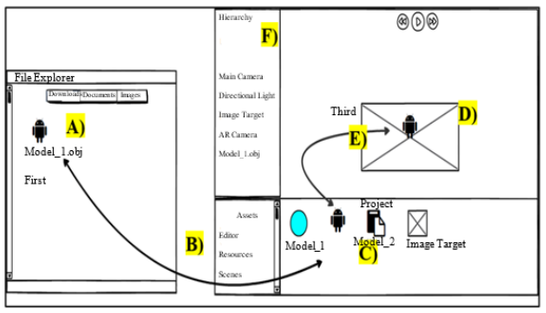

Figure 4
Title: 3D Modelling

Source: Own elaboration, 2024

Workflow:

A. Camera display.
B. Scan image target.
C. 3D model display.

Coding

In this phase, a complete installation manual has been developed to provide a step-by-step guide for the installation of the Unity graphics engine. This manual also includes the integration of the Vuforia SDK, an advanced tool that allows access to a robust set of features and functionalities.

Thanks to the implementation of Vuforia in Unity, it is possible to enhance the development of applications that require the visualisation of 3D models using Augmented Reality (AR) technology, facilitating the creation of interactive and immersive experiences.

AR glasses with Lends Studio, a virtual augmented reality glasses creator has been developed using Lens Studio, designed to deliver a personalised and engaging experience. During the creation process, tools such as Affinity Photo were used for filter editing and texture adjustment, which were then exported to Lens Studio. The project included downloading lens models from Sketchfab, which were imported and adjusted in Lens Studio to perfectly fit the user's face.

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To try on the lenses, it is necessary to use the Snapchat app, which is downloaded to the mobile phone, allowing an immediate and realistic visualisation of the lens models. It is an idea for a customer to try out how they would look with this product.

Testing

A checklist was created detailing the essential steps for the development of an augmented reality (AR) application using Unity and Vuforia. Key aspects such as the installation of the Unity graphics engine, the incorporation of the Vuforia SDK, and the implementation of 3D models and Image Targets are evaluated. In addition, the correct functionality of the application is verified in terms of camera permissions, Image Targets detection and 3D model visualisation. Each element is reviewed to ensure compliance, allowing to document whether the requirements have been met and to record relevant observations that may arise during the development process.

Release

The applications that were realised with the AR Technology creation and visualisation tools are essential to support industries in attracting the attention of the general public, as well as in the educational field.

Results

As a result of this project, three aspects were focused on, the first one was to make sure that the students had knowledge about this technology, so numerical, hand-drawn and graphical activities were carried out to make them understand the basic knowledge. In addition, a Vuforia with Unity manual was developed from installation to the creation of 3D models and APKs.

As a second aspect, objects were designed and developed in AR in pairs, as the sub-academy decided that in this way it would support micro-enterprises in the region, with a transversal and integrative project that would be scaled throughout the four-month periods, thus ensuring

- The system conditions: correctly installing the Unity graphic engine, the incorporation of the vuforia SDK, the incorporation of the Image Target and the incorporation of the 3D Model.

- AR element designs were created: images in PNG or JPG format were imported, the quality of the images was analysed and the incorporation of the image into the Image Target was analysed.

- In terms of functionality: ensured that permissions were granted to access the camera and that the application would detect the Image Target via the device's camera; determined that the application would display the 3D model.

- Coding: In coding it was important to consider that the platform was Androi, configure the minimum Api for the operation of the application, create the application installer (APK).

The third point was to ensure that students understood the application and use of AR as part of their professional training and the added value in their projects, the following activities were carried out:

- Students taking the subject multivariable calculus will be able to enhance the learning of complex concepts through interactive visualisation of 3D graphics.

- Support education and training through simulations and visual tools that improve knowledge retention.

- Offer the possibility to interact with products tailored to individual preferences.

- Attract and maintain user interest through immersive visual experiences.

- Create unique experiences that differentiate brands, using emerging technologies.

- Provide tools that allow ideas to be explored and visualised more effectively.

- Develop new ways of interacting with content, enhancing the user experience.

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- Develop new ways of interacting with products and services, differentiating market offerings.

A project was carried out in the MATLAB tool in which a 3D surface graph was generated using the 'x', 'y', and 'z' matrices with the 'surf' function, which creates a three-dimensional mesh representing the surface defined by these points. It then exports this 3D model to an STL file with the name 'parabolic_model.stl', using the 'stlwrite' function, which is useful for 3D printing applications or CAD software. Finally, it saves the generated graph image as a PNG file named 'graph_surface.png' using 'saveas', allowing the result to be visually documented. This process ranges from viewing and exporting the 3D model to generating a static image of the graphic.

Box 5

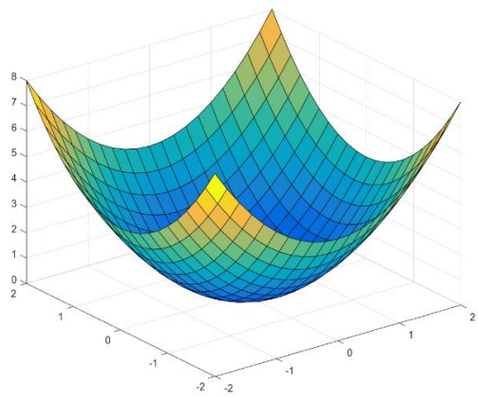

Figure 5
Title: Graphing in Matlab

Source: Own elaboration, 2024

As you can see, the image is scanned and as a result the 3D model is visualised by integrating Vuforia with Unity.

Box 6

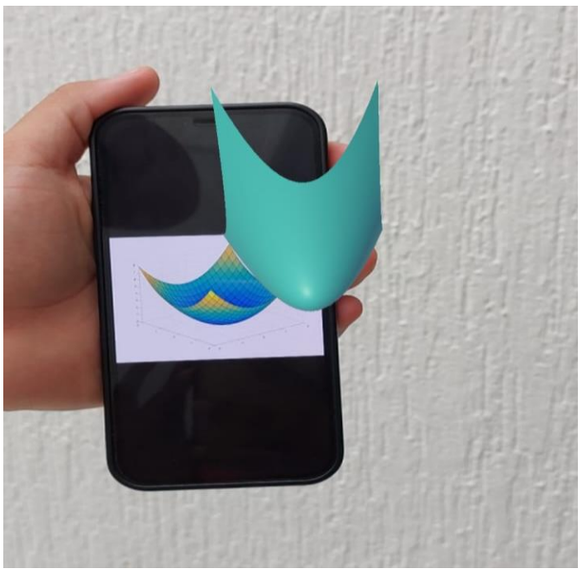

Figure 6
Title: Graphing in Matlab using Vuforia with Unity

Source: Own elaboration, 2024

Another outstanding application was for students to visualise how classroom knowledge using AR technologies can be applied to product sales, offering potential customers an experience closer to the reality of the product being offered.

a) The first team designed a website for a bakery in the region and as can be seen using Unity and Vuforia the customer's shopping experience was improved.

Box 7

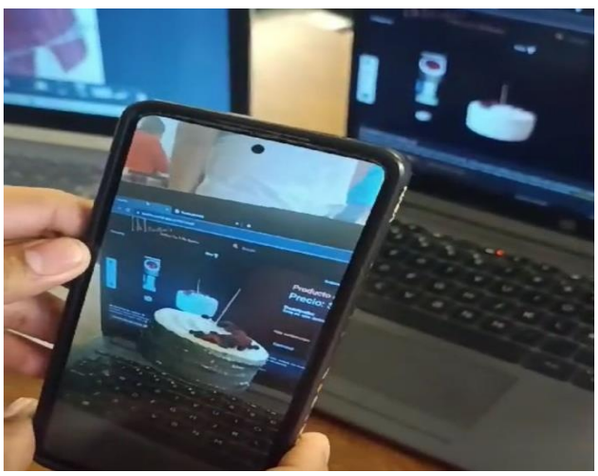

Figure 7
Title: Visualisation result of 3D model of pastry shop using Vuforia with Unity

Source: Own elaboration, 2024

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b) Another team developed as a project a website for the sale of computer equipment and applied augmented reality in the following way.

The software made it possible to show computer equipment accessories modelled in 3D.

Box 8

Figure 8

Title: 3D mouse model visualisation result using Vuforia with Unity

Source: Own elaboration, 2024

Box 9

Figure 9

Title: Visualisation result of 3D model visualisation of hearing aids using Vuforia with Unity

Source: Own elaboration, 2024

c) This team models products for a gift shop.

Box 10

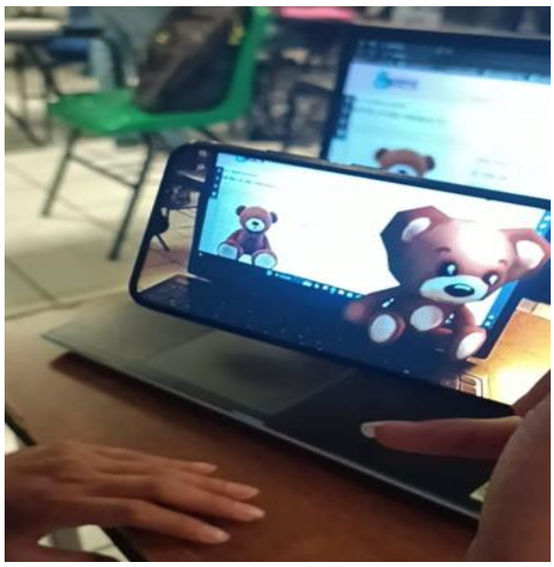

Figure 10

Title: Result of 3D Model Visualisation using Vuforia with Unity

Source: Own elaboration, 2024

Integrating Vuforia in Unity allowed the creation of augmented reality (AR) applications for mobile devices in this project the Android operating system was used, tests were conducted to determine how Vuforia works in Unity using Image Targets and 3D Models, an installation manual was developed focused on beginners so that they can integrate their knowledge, practical problem solving, interactivity and meaningful learning.

Conclusions

New applications and new ideas to be implemented emerge practically every day and this innovative force will grow with wearable devices. To get an idea, a search in Google's Android application repository (playStore) for the term augmented reality returns more than two hundred different applications and rising almost every day. The motivational elements of the use of the technology are now sufficiently proven to be beyond dispute and many authors argue that AR technology actually serves to improve educational practice and students' understanding of certain aspects of reality.

ISSN: 2531-2162
RENIECYT-CONAHCYT: 1702902

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It has also been used to provide practice to learners (medical applications) that would otherwise be impossible to provide with real subjects.

The world of marketing and advertising is no stranger to this technology and as an example we can see how the multinational furniture company IKEA has launched its catalogue with AR since 2014.

This work shows how the combination of knowledge and technology can change the perspective of the application of AR in local commerce and in any MSME, as well as offering students a way to visualise not just numbers but knowledge applied to the real world. It focused on the installation and configuration of the Unity graphics engine and the acquisition of Augmented Reality (AR) skills for application in industries such as education and product marketing. The Vuforia SDK, essential for developing AR-based applications, was also integrated. The implementation of these technologies offers significant added value, as their use is not yet widespread in both sectors, making them a visually appealing tool with high innovative potential. In addition, MATLAB was installed and interfaces were developed to efficiently calculate and graph results, facilitating the visualisation and analysis of complex data, essential for informed decision-making and process optimisation in various areas.

During the planning phase, extensive research was carried out to select the best tools for AR. MATLAB was chosen for the creation of 3D mathematical graphics because of its powerful graphics engine, while Unity, together with Vuforia, was selected for the development of AR applications because of its image recognition and digital element overlay capabilities. Lens Studio and Meta Spark Studio were chosen to create AR experiences in social networks. In the design phase, detailed mockups were created in Balsamiq to visualise the structure and flow of the application, anticipating challenges and aligning the visual aspects with the technical requirements of the project.

During coding, several applications were integrated into Unity and a detailed manual was developed for the installation and configuration of Unity and Vuforia, including functional testing. In addition, an interactive quiz application and an interactive filter were created in Meta Spark Studio. In the testing phase, the correct installation and configuration of Unity and Vuforia was evaluated, verifying the integration of Image Targets and 3D models, the configuration for Android, and the generation of the APK, ensuring a smooth user experience. Applications developed with AR offer significant value in education and industry, facilitating learning through interactive visualisations and customised simulations, and differentiating brands in the market.

During the tests, 60 students from the Information Technology course were involved, and it was undoubtedly an experience that allowed for a better relationship between numbers, products, customers and technology.

Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that might have appeared to influence the article.

Authors' contribution

Del Carmen-Morales, Yucels Anaí: Contributed research idea, project management, coding of AR applications and instrument design for testing.

Del Carmen-Morales, Heidi: Participated in the design phase and selection of elements to be coded to make the 3D models.

Felipe-Redondo, Ana María: Participated in the planning phase, which included academic meetings, integration of work teams and contact with MSMEs in the region.

Juárez-Castillo, Efrén: his specialisation in artificial intelligence and programming strengthened the fulfilment of the objectives and the feedback on the tests.

ISSN: 2531-2162
RENIECYT-CONAHCYT: 1702902

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DOI: https://doi.org/10.35429/JAD.2024.8.19.1.13

Availability of data and materials

The data, results and information collected are available for consultation upon request to the corresponding author.

Funding

This research did not receive any funding, but was carried out with equipment and resources from the CATI Academic Team in Information Technology.

Abbreviations

List abbreviations in alphabetical order.

QR	Rapid Response Code
CATI	Academic Body in Information Technologies
CAD	Computer Aided Design
2D	Two-dimensional
SDK	Software development kit
MATLAB	Matrix laboratory
SLAM	Simultaneous localisation and mapping
B2C	End market
Mipymes	Micro, small and medium enterprises.
APK	Android application package
XP	Extreme programming
POIs	Points of Interest
AR	Augmented Reality
GPS	Global Positioning System
iOS	iPhone operating system
3D	Three-dimensional
UTHH	Technological University of Huasteca Hidalguense

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ISSN: 2531-2162
RENIECYT-CONAHCYT: 1702902

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DOI: https://doi.org/10.35429/JAD.2024.8.19.1.13

Journal of Architecture and Design 8[19]1-13: 40819113
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Prendes, C. (2015). *Realidad Aumentada y la educación: Experiencias practicas*.

ISSN: 2531-2162
RENIECYT-CONAHCYT: 1702902

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