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INNOVACIÓN EDUCATIVA EN EDIFICACIÓN

Immersive technologies in the teaching of non-structural seismic risk: development of an app with augmented reality and Artificial Intelligence for architectural education

Tecnologías inmersivas en la enseñanza del riesgo sísmico edilicio no estructural: desarrollo de una app con realidad aumentada e inteligencia artificial para la educación en arquitectura

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HIGHLIGHTS

- A digital augmented reality application with integrated AI was developed.
- Non-structural vulnerability was addressed through an innovative educational initiative.
- A digital tool was designed to promote awareness and education on earthquake preparedness.
- Immersive technology was used to enhance teaching in architectural education.
- A chatbot with specialized responses was integrated into the educational application.

TITULARES

- Se desarrolló una Aplicación Digital de Realidad Aumentada con IA integrada.
- Se utilizó tecnología inmersiva para potenciar la enseñanza en arquitectura.
- Se abordó la Vulnerabilidad no estructural con una iniciativa innovadora para la educación.
- Se diseñó una herramienta digital orientada a la concientización y educación ante sismos.
- Se incorporó un chatbot con respuestas especializadas en Aplicación educativa.

ABSTRACT

We are currently witnessing a digital revolution in which students, from an early age, are in constant contact with devices and technologies in their daily activities. This digital transformation in education not only changes what we learn, but also how we learn it, highlighting the need for new educational approaches. In this context, the integration of Artificial Intelligence (AI) into educational applications helps enhance students' learning competencies.
The province of San Juan is located in the area of highest seismic hazard in Argentina, according to the zoning of the National Institute of Seismic Prevention (INPRES), and has historically been affected by numerous earthquakes, resulting in significant human and material losses. While the development of seismic-resistant regulations has considerably reduced structural risk, non-structural seismic risk remains a critical issue that can cause substantial material damage and endanger lives. This article presents the development of an educational application that addresses the topic of non-structural seismic risk through Augmented Reality, integrating AI tools to provide information to users via an embedded chatbot. The main objective of this innovation is to raise awareness and improve preparedness in the event of an earthquake, contributing to architectural education through new forms of immersive learning.

Keywords: *Seismic risk, Augmented reality, Artificial intelligence, Non-structural vulnerability*

RESUMEN

Atendemos en la actualidad a una revolución digital, en la que desde edad temprana los estudiantes están en contacto constante con dispositivos y tecnologías para realizar las actividades diarias. La revolución digital en la educación condiciona lo que sabemos y cómo lo aprendemos, relacionándolo con la necesidad de un nuevo planteamiento educativo. En este contexto, la integración de la Inteligencia Artificial (IA) en aplicaciones educativas ayuda a potenciar las competencias de aprendizaje de los estudiantes.

La provincia de San Juan se ubica en la región de mayor peligrosidad sísmica de la República Argentina, según la zonificación del Instituto Nacional de Prevención Sísmica (INPRES), y ha sido históricamente afectada por numerosos terremotos que han dejado un alto saldo de víctimas y daños materiales. Si bien el desarrollo de normativas sismorresistentes ha permitido reducir significativamente el riesgo estructural, el riesgo sísmico no estructural continúa siendo un factor crítico que puede generar importantes pérdidas materiales y poner en riesgo la vida humana. El presente artículo aborda el desarrollo de una aplicación que incorpora los conceptos de la temática del Riesgo Sísmico edilicio No Estructural abordada bajo la lente de la Realidad Aumentada, incorporando herramientas de IA para que, a través un chatbot de IA integrado, aporte información al usuario, en el ámbito educativo, cuyo objetivo es concientizar y mejorar la respuesta ante la ocurrencia de un evento sísmico, como aporte innovador a las formas de educación en la Arquitectura.

Palabras clave: *Riesgo Sísmico, Realidad Aumentada, Inteligencia Artificial, Vulnerabilidad no Estructural*

1. INTRODUCTION

According to the EM-DAT International Disaster Database, 432 disasters caused by natural phenomena were recorded worldwide in 2021. These events resulted in approximately 10,500 deaths, affected over 102 million people, and generated more than 252.1 billion dollars in economic losses. In the current decade, the most catastrophic disasters in terms of loss of human life have been caused by earthquakes (Bello et al., 2020). For this reason, the region is engaged in significant efforts to mitigate disaster risks, adapt to the effects of climate change, and reduce vulnerability to such events. The Province of San Juan is located in the central-western region of the Argentine Republic and lies in the area of highest seismic risk. This is due to its proximity to the convergence point between the Nazca and South American tectonic plates (Ortiz, 2021).

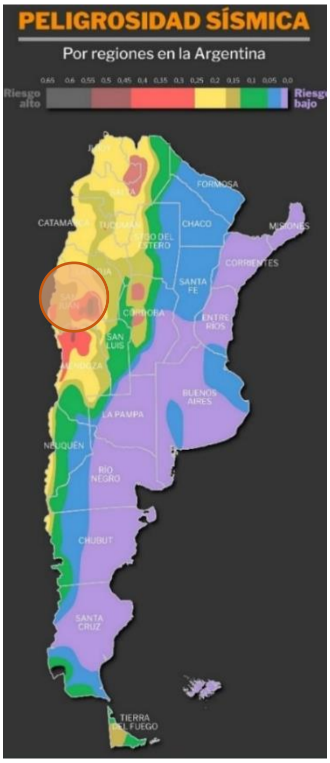

Fig. 1: Seismic risk map of Argentina. Source: Infobae.

Risk has a complex structure that essentially includes the concepts of hazard, vulnerability, and resilience. In this sense, a hazard is understood as the potential manifestation of a phenomenon capable of producing adverse effects on elements within a given territory, due to their predisposition to be affected by such a phenomenon and their limited capacity for recovery afterward. Specifically, seismic risk refers to the seismic hazard inherent to the geophysical characteristics of our territory. To develop strategies aimed at reducing the levels of risk to which a community is exposed—and to prevent a disaster from occurring—it is essential to have a clear understanding of the community's vulnerability in the face of that hazard (Scognamillo, 2022).

As mentioned earlier, one of the main natural environmental threats in the Province of San Juan is seismic hazard. Therefore, identifying, assessing, and spatially visualizing the levels of vulnerability associated with seismic hazard in the San Juan territory is considered a top priority for mitigating the potential adverse effects of a high-intensity earthquake.

Augmented Reality (AR) refers to a technology capable of enhancing the perception and interaction with the real world by providing users with a real environment augmented by additional computer-generated information (Orozco, Esteban, Trefftz, 2006).

In this context, both research and classroom experiences with Augmented Reality (AR) show that it has rapidly entered academic environments (Barroso Osuna et al., 2017; de la Horra, 2017; Moreno Martínez & Galván Malagón, 2020; Hou et al., 2021). When analyzing and comparing the use of these technologies in educational settings, several benefits have been observed—particularly the improvement of students' spatial intelligence through the use of AR-based digital technologies (del Cerro Velázquez & Méndez, 2017). Existing AR production software offers multiple possibilities for its integration into educational environments (Cabero Almenara & Barroso Osuna, 2018).

Some studies have explored the perceptions of secondary school students regarding the use of these technologies in their learning process. These studies conclude that students believe such technologies can be effectively used in educational settings (Marín–Díaz et al., 2022). In light of findings from various studies—particularly the Horizon Reports it is reasonable to consider that we are witnessing the consolidation of several trends in the educational use of emerging technologies. Among these, mobile devices, 3D modelling, and augmented reality (AR) stand out (Almenara & Cejudo, 2019).

Learning and Knowledge Technologies (TACs) have thus emerged as key allies in renewing pedagogical practices, as they enable the design of dynamic, interactive, and personalized learning environments tailored to the characteristics of each student (Smith & Brown, 2021).

In Argentina, mobile phones are the most widely used technology among both young and adult populations. From age 18 onwards, mobile phone use surpasses that of computers and internet. Among children and adolescents aged 4 to 12 and 13 to 17, internet usage exceeds mobile phone usage and, of course, also computer use. In the 4 to 12 age group, internet use exceeds mobile phone use by 20.7 percentage points. Teenagers aged 13 to 17 are those who use computers the most (50.3%). Among individuals aged 18 to 29 (98.0%), mobile phone usage is the highest compared to other age groups, followed closely by the 30 to 64 age group (97.5%).

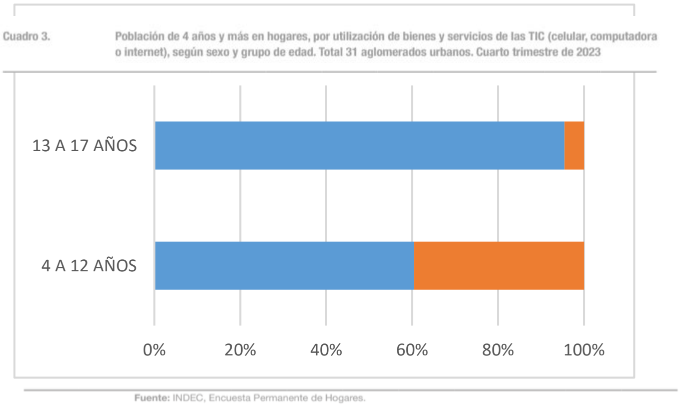

Fig. 2: *Percentage of mobile device usage by age group.*

These data indicate that mobile devices are the most widely used and therefore the most suitable option for our objective.

The digital revolution in education shapes both what we know and how we learn it, highlighting the need for a new educational approach and the acquisition of new competencies through the integration of these digital resources into the learning process (Engen, 2019). Additionally, the integration of Artificial Intelligence (AI) into educational applications helps enhance students' learning competencies (Alhumaid, 2023). AI should be leveraged in the field of education to improve both learning outcomes and student performance. To achieve this, various technologies can be employed, such as virtual reality, augmented reality, and educational games, among others (Castrillón, 2020).

In education, as a central axis, the goal of using AI alongside various fields of pedagogical knowledge is to develop programs that enable adaptive and personalized learning environments. This aims to promote specific strategies for knowledge acquisition tailored to each student; while also feeding information back to the AI so it can generate possible strategies to deliver knowledge more effectively (Moreno Padilla, 2019).

The use of AI in education has led to the creation of innovative resources and tools, such as online learning platforms, intelligent tutoring systems, and personalized learning programs. These are designed to provide tailored responses to each student's needs in order to improve the overall learning experience (Aldosari, 2020; Chen et al., 2023; Chiu et al., 2023; Singh et al., 2022; Srinivasa et al., 2022; Yang et al., 2022). Advances in AI systems are giving rise to new tools in the educational field, such as chatbots, which can be highly useful (Segovia-García, N. & Segovia-García, L., 2024). This element is one of the central aspects of our work, since the implementation of chatbots with integrated AI provides a communication interface between the user and the digital application. Through this interface, users can receive targeted responses to specific questions based on curated topic databases, offering specialized and guided answers.

A chatbot is a software program that uses structured messages to deliver responses from a machine to a human user, offering instant, personalized, and readily available services (Manjarrés-Betancur & Echeverri-Torres, 2020). Within this context, the main objective of this project was to develop an Augmented Reality application with an AI-powered chatbot that allows users to visualize 3D iconography designed to inform about life-threatening risks to building occupants.

2. MATERIALS AND METHODS

2.1 Methopology

This work is an example of applied research (action research) and includes objectives related to a Technological and Social Development Project currently being developed by our research team.

The methodology followed a sequence of stages: design, creation, programming, and verification.

Design: Before developing and programming the application, a set of graphic sketches was produced to define the interface layouts envisioned for the different functional states of the app. Initial drafts of the user interfaces were created to represent the early ideas for the final application. These were progressively refined with added features and elements until the final version was achieved.

For the development of the application, Unity was chosen due to its status as open-source software, where the products created within the platform remain the property of the user. This means that the program can be used by anyone or any institution with the appropriate knowledge. As open-source software, it allows the development of games or applications in which the creator is permitted to freely use the final product—in our case, for academic purposes. The owner of the open-source license grants users a range of freedoms not provided by proprietary software licenses, which retain numerous rights under intellectual property laws (Adell & Bernabé, 2007).

Create: Prior to programming the app, the user interfaces were built using Unity's User Interface tools, and the 3D models of the icons integrated into the app were modelled beforehand.

Program: Once the interfaces were created—including the different screens the user would interact with, the buttons on each screen, and their placement—scripts were incorporated to control the application's functions. A script is an informal term for a programming language used to manipulate, customize, and automate events within an existing system. In this case, scripts were used to assign and program the functions of each button to ensure the correct operation of the application.

Verify: The verification of the application's proper functioning was a cross-cutting process throughout all stages of its development. At each key step, efforts were made to ensure that the progress made up to that point was functioning as expected. Upon completion, a final verification of the application was carried out to confirm that all actions operated correctly and in a coherent, integrated manner.

2.2 Stage I: Application Development

When the application is launched and camera permissions are enabled, the architectural space is scanned using a point cloud system that recognizes significant points in the space where the user is located. A simple interface displays a menu showing the 3D models available in the application's database.

Once the chosen icon model has been selected, it can be placed in the space, rotated, and positioned. Thus, once the model has been fixed, it remains in the position in which it was placed, and the user can continue to move around the space and place new icons. As long as the camera points to where the previous icons were placed, they will be visible in the same position. Once the application is closed, the previously set icons disappear. With the icons in place, you can take pictures of them, and the application automatically displays options for sharing the photo on social networks such as WhatsApp, Instagram, etc.

The application was developed in eight stages:

1. Application design
2. Interface design
3. Point cloud detection
4. Integration of 3D models into the application
5. “Position models” function
6. “Rotate and select” functions
7. “Take augmented reality photo” function
8. AI chatbot integration

Each of these stages was developed in the Unity video game design program, complemented by Visual Studio, which allows scripts to be written and incorporated into Unity.

1. Application design

The application has three states:
• Main menu: Where the application starts and where you can see the 3D icons fixed in augmented reality.
• Items menu: Here you will find the bar with the available icons to select.
• Positioning in augmented reality: Where you can operate the icon by positioning, rotating, scaling, and fixing it.

2. Application Design

With the application states established, you can begin designing the application interface. To do this, the icons to be used for each of the application buttons were previously designed in Photoshop. The PNG images are imported into Unity to incorporate them.

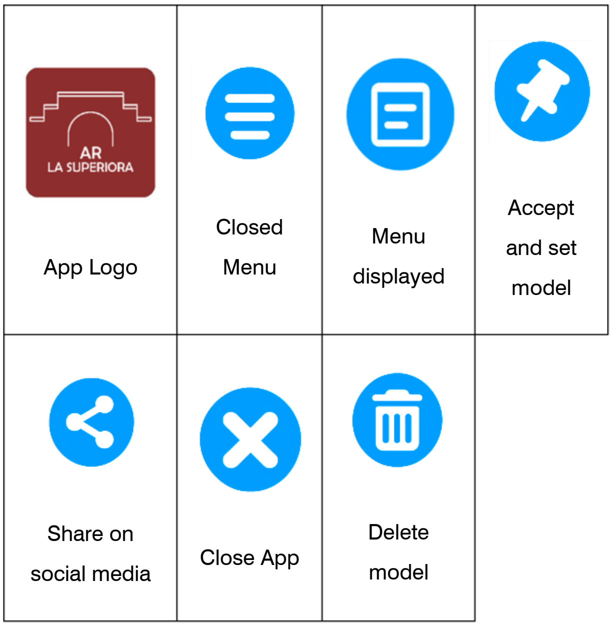

Fig. 3: *Graphic icons designed for each of the buttons included in the application. Source: Own creation.*

Main Menu Interface: The main menu interface will have three buttons: A main “open item menu” button located at the bottom centre of the canvas, which will be the button that displays the icon menu when interacted with. An application close button at the bottom left, and a button to take a screenshot and share at the bottom right of the interface.

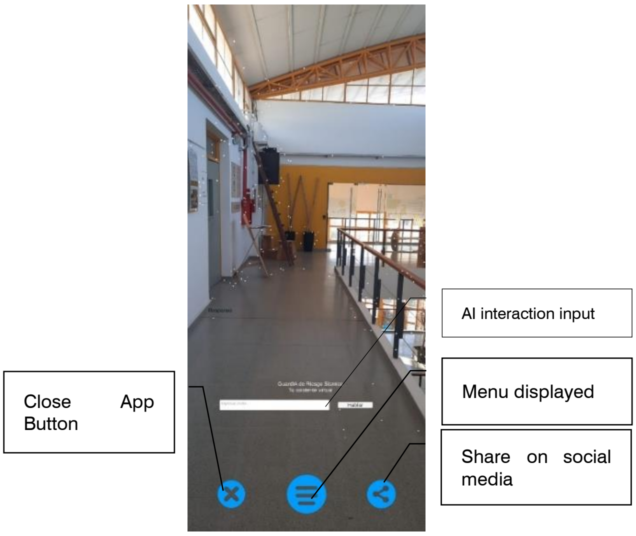

Fig. 4: *Main menu interface of the application in operation. Source: Own creation.*

Icon Menu Interface: This interface, which is activated after tapping the main button on the previous interface, has two parts. A button in the same position as the main button on the previous interface, which graphically indicates that the item menu is displayed, and a "Scroll View." In the Scroll View content, buttons were created and stored there, each of which contains a 3D model of the icon they represent, linked to it.

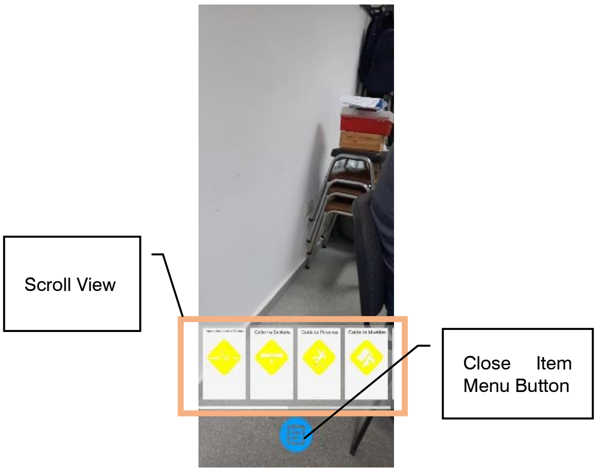

Fig. 5: *Icon menu interface of the application in operation. Source: Own creation.*

Augmented Reality Positioning Interface: This application status will only have two buttons. A "delete" button, which will allow you to delete an icon that has been placed and you want to remove, and a "Fix Icon" button that allows you to fix the model in the position chosen by the user so that it remains in place.

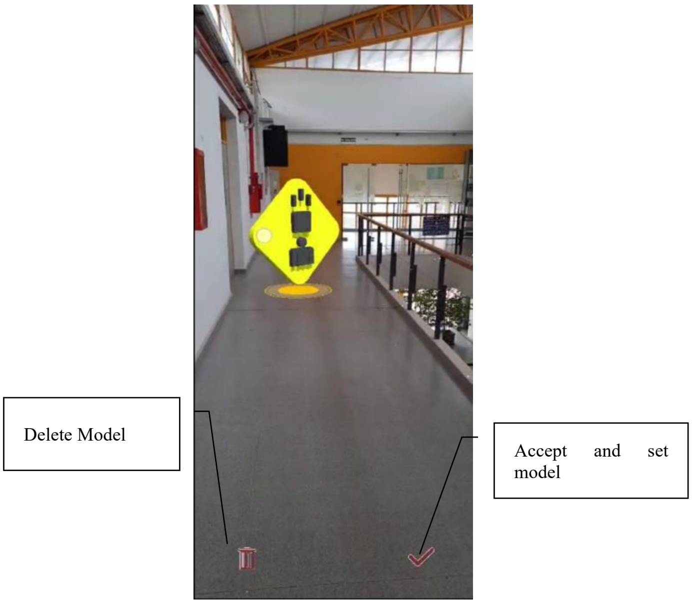

Fig. 6: *Augmented Reality Positioning Menu interface of the application in operation. Source: Own creation.*

3. *Space detection with Point Cloud*

In order for the application to be able to detect the characteristics of the space, a camera was first incorporated into the application, allowing the mobile device's camera to be used to view the space. To do this, an "AR Session Origin" element was added to the application in Unity, which contains a camera for augmented reality applications.

To detect the notable characteristics of the space in which the user is located, a particle system was built to render a point cloud system. To do this, a component called "AR Point Cloud Manager," which is native to Unity, was added to the development and assigned a "Prefab," which is an element that contains the graphic information that the particles will use and the particle system configuration. Thanks to the prefab built to contain the particle system, the point cloud can be seen. The points in the point cloud are usually notable features of the environment that the device recognizes, such as characteristic elements, walls, and floors.

4. Integration of 3D models into the application.

To integrate the 3D models of the iconography into the application, "Scriptable Objects" were used, which is a Unity tool for saving and organizing information in Unity. An item template was created that contains the object's information, such as name, image, description, and 3D model.
To assign each button the information corresponding to its icon, the image that represents it, a brief description of it, and the 3D model that should appear in augmented reality when selected, the aforementioned template is used.

- Icon Name
-Icon Image
-Brief Description
-3D Model

Information visible on buttons

For the iconography, 3D models taken from the work of the research team at the Non-Structural Seismic Risk Office were incorporated into the application. "Iconography as a tool in augmented reality technologies to visualize seismic risk in buildings. FAUD case" (Guillén & Heredia 2021).

The icons developed in the research work "Immersive technologies for the assessment and analysis of seismic risk in educational establishments" (Heredia et al., 2022) were also used.

However, due to the need to incorporate the icons into a mobile device screen, work was done to adapt the iconography taken from the aforementioned works, simplifying and adapting the icons to achieve a better understanding of them, with a primary school user in mind. To this end, the proposal of this work was to work with strategies of solids and voids, so that the characters in the icon are the voids within the icon's frame.

Fig. 7: *Icons taken from: "Immersive Technologies for the Assessment and Analysis of Seismic Risk in Educational Buildings" (Heredia et al., 2022)*

5.; 6.; 7.: Functions "Position Models," "Rotate and Select Models," "Take Augmented Reality Photo"

At this point, once the 3D models of the icons were incorporated into the application, the scripts were created to control interactions with them, allowing the user to move, rotate, and scale them.

In this way, the functions that allow the models to be controlled in augmented reality for the correct functioning of the application were finally integrated into the application.

8. AI Chatbot Integration

The incorporation of Artificial Intelligence into the application's operating processes was established as a stage subsequent to its development. In other words, the first stage involved getting the augmented reality and iconography up and running in the application, while the second stage—still in development—involves incorporating AI with the aim of adding an AI chatbot that can autonomously respond to users with additional information. This was done in order to "compartmentalize" the results, since attempting to incorporate AI technology during the development of Augmented Reality ran the risk of damaging one or the other program.

The objective of incorporating one into the application is to streamline the learning processes by giving the user the possibility of clearing up doubts with a "specialized" agent within the application itself. In other words, the chatbot, which was given instructions on how to respond and what bibliography to base its responses on, allows users to ask specific questions such as “What is seismic risk?” “What elements represent a vulnerability in a building?” or any other questions the user may have.

To incorporate AI into the existing application, it was necessary to select a pre-developed AI model and a script that would allow a series of input and output text boxes to be introduced into the application, in which questions could be entered and answers displayed. In this context, it was decided to use the Gemini AI engine developed by Google.

After incorporating the chatbot into the app, it was provided with a database of the team's work and bibliography used under the instruction: "You are a virtual assistant specialized in seismic risk, building safety, and hygiene. Respond with clear, professional, and educational language, based on current technical approaches and the IRPHa-CONICET research on non-structural elements and architectural risk prevention."

3. RESULTS AND DISCUSSION

The incorporation of digital technologies in architecture education is an almost necessary innovation today, given the many benefits it offers in terms of understanding the subject matter due to its dynamic nature, which engages the user by allowing them to be an active participant in the teaching-learning process. In this case, it allows them to place the icons themselves, requiring them to first understand the meaning of each one and the risk involved.
Once the application was developed, it was verified against the functions that were proposed at the beginning. The application was successfully implemented, allowing for the visualization and teaching of seismic risk in architecture, achieving an innovative teaching tool in the field of application.

Fig. 8: *Laboratory and field tests of the application's performance. Source: Own elaboration.*

The functional verification yielded satisfactory results in the application in case studies, achieving its integration into the teaching processes at the Faculty of Architecture, Urbanism, and Design, in the Chair of Non-Structural Seismic Risk Management.
The artificial intelligence incorporated into the specialized chatbot in the application made it possible to streamline the processes of understanding and clarifying doubts among students independently and effectively.

Fig. 9: *AI chatbot performance test. Source: Own creation.*

Through the interaction box, users can view and analyse vulnerabilities in the building in augmented reality while exchanging queries with the chatbot to clear up any doubts that may arise at the time. The chatbot contains bibliographic information related to the subject matter, reviewed or written by the team, allowing it to provide accurate answers without conceptual deviations.
The use of the digital App developed was also incorporated into an integration proposal made by the National University of San Juan with primary schools in the province, in a real approach to applied research in the education of children in schools.

***Fig. 10:** Field test with primary schools in the province. Presentation of the app to a fifth-grade class at a primary school. Source: Own work.*

Innovation in teaching methodology was a distinguishing factor in the children's experience, as they quickly embraced it and incorporated the concepts in a playful and educational way, detecting vulnerabilities in Augmented Reality and interacting with the Chatbot to clear up their doubts.
Given the applied research spirit of this work, the real experiences of exchange with students are fundamental to understanding how digital technologies work in education. The feedback received from students allows us to evolve teaching and learning processes, seeking new opportunities and paths for innovation.

***Fig. 11:** Testing app in the case study building "Complejo la Superiora." Source: Own elaboration.*

In areas with high seismic risk characteristics, such as San Juan, Argentina, it is important to take action in the training of our students, particularly those involved in architectural design and construction, so that risk mitigation measures are present from the earliest stages of a project.

Advances in the use of immersive technologies and AI in education allow for the development of new paradigms in teaching and learning processes, in which students actively participate not as actors who "receive knowledge" but as a fundamental part of the development of new disciplinary bodies driven by digital processes.

4. CONCLUSIONS

The development of a virtual reality application with built-in artificial intelligence demonstrated the potential of immersive technologies to improve teaching and learning processes in architecture, particularly in the area of non-structural seismic risk in buildings. This tool allowed students to visualize building vulnerabilities and interact with the specialized chatbot directly in the space. This approach contributes not only to the understanding of the concepts incorporated but also to the preparation of students from the early stages of education to respond to seismic events.

The integration of the chatbot with artificial intelligence enriched the user experience by allowing for independence from the process, enabling interaction with a specialized artificial intelligence agent. This feature proved effective in consolidating learning processes, reducing conceptual ambiguities, and promoting autonomous exploration among students. Furthermore, the incorporation of the application into primary education settings revealed the versatility of the tool, highlighting its capacity to adapt to diverse educational levels and contribute to risk awareness at a broader social scale.

In conclusion, this paper seeks to demonstrate that the convergence between Augmented Reality and Artificial Intelligence are innovative tools that can help improve teaching and learning processes by adapting to the digital revolution we are witnessing. This proposal seeks to contribute to the construction of a more resilient society through the incorporation of innovative tools for education in architecture.

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