Design of a resistor using Geometric Modeling to be included in a virtual laboratory and DEVELOP a DC circuit practice

Diseño de un resistor a través del Modelamiento Geométrico para incorporarse en un laboratorio virtual y desarrollar una práctica de circuitos DC

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Abstract

This document presents the results of the research framed in the project named Design of a Virtual Laboratory to the Circuits Analysis and Instrumentation, using Geometric Modelling, where a basic element as the resistor is proposed to the development of exercises improving the basic skills in circuit analysis, according to the background about virtual laboratories usage in engineering education. Also, this research got the characterization of basic resistive elements to subsequently begin with complex designs as photoresistors whose behavior is similar. In this exercise some resources were used as well as Autodesk Maya to the physical structure of the element, and Unreal Engine to define the element's interaction into the laboratory. The methodology of the design fits into the stablished one in project to define the mathematical equation that describe its behavior in similar conditions as reality and its virtualization to be included in virtual laboratory to finally end up with the validation of performance. As a result,

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the construction of a resistive device that represents the behavior as in reality was developed, and its satisfactorily incorporated into the virtual laboratory.

Keywords: 3D, Blueprint programming, Electronic, Resistive circuits, Resistor, Virtual Laboratory.

Resumen

Este documento presenta los resultados de la investigación enmarcada en el proyecto denominado Diseño de un Laboratorio Virtual para la Práctica de Análisis de Circuitos e Instrumentación, por medio de Modelamiento Geométrico, donde se propone un elemento básico como el resistor para el desarrollo de prácticas que fortalezcan la apropiación de competencias básicas en análisis de circuitos, teniendo en cuenta los antecedentes del uso de laboratorios virtuales para la formación en ingeniería. Con esta investigación se logra la caracterización de los elementos resistivos básicos para posteriormente pasar a diseños más complejos. Para este ejercicio se utilizaron diferentes herramientas como Autodesk Maya para el diseño de la estructura física del elemento, y Unreal Engine para definir las interacciones del elemento en el laboratorio. La metodología de diseño se ajusta a la establecida en el proyecto para definir la ecuación matemática del comportamiento del elemento que represente su funcionalidad en similares condiciones a las reales y su posterior virtualización para incluirse en el laboratorio virtual para finalmente terminar con la validación de funcionamiento. Como resultado se logra la construcción de un dispositivo resistivo que representa el comportamiento en la realidad y que se incorpora satisfactoriamente en el laboratorio virtual.

Palabras clave: 3D, Circuitos Resistivos, Electrónica, Laboratorio Virtual, Programación Blueprints, Resistor

1. Introduction

Nowadays, different technologies have become important in engineering education, and practices using virtual scenarios are becoming in an excellent opportunity to support and complement the learning processes involved [1]. Likewise, in electronic training, these scenarios include controlled environments where the user can reproduce experiments, in which variables are usually monitored to observe the behavior of electronic equipment or circuits, and the virtuality allows the users to get the experience using laboratory elements before they reach the real ones [2], [3].

Moreover, one of the basic elements in electronics is the resistor, because shows the students the concept of Ohm Law and the behaviour of current and its relationship with variables as voltage and resistance. On the other hand, the pandemic around the world since 2019 because of SARS COV 2 lead the universities to rethink the practice scenarios because of the restrictions to the population in terms of mobility.

Around the world, many different universities and the researches have shown that virtual laboratories offers an opportunity to the students because they can use it anytime and present an environment similar to reality, strengthening different skills in theoretical and practical knowledge. For example, the Universsdad Politécnica de Madrid, where the students can reproduce a practice in similar conditions to reality; Also authors as Ibarra, C. Medina, S. & Bernal, A. (2007) or Machado, G, Álvarez, M. & Suarez, S. (2018). (OJO, TOMADOS DE LA PROPUESTA DEL PIE) shows the viability of the use of virtual laboratories to reinforce theoretical concepts in learning process.

At the National Open and Distance University of Colombia - UNAD, academic programs such as Electronic Engineering and Telecommunications Engineering are offered for students to follow a specific study plan for each program. Some courses have practical face-to-face components, where students apply the theoretical knowledge learned and are also trained in technical aspects such as manipulation of instrumentation equipment for the design and testing of electronic circuits, Therefore, by monitoring the development process of these laboratories, the need for a tool that allows to strengthen the manipulation of electronic instrumentation equipment for measurement, feeding, and other elements required in an academic exercise, was identified [4], Consequently, a virtual lab with laboratory is proposed, providing the development of tests for analysis of resistive circuits by means of elements modeled in three dimensions [5]–[9].

This context presents an opportunity to research and propose a virtual laboratory to the develop of circuit analysis and instrumentation practices, using geometric modelling in 3D and characterize the resistor.

2. Proposed methodology to the virtual laboratory and the resistor

2.1. Methodological planning stage

The methodology applied in the research project is presented in Figure 1, the general scheme used for the development of the virtual laboratory and the resistor is presented, where the first stage is the recognition of the project that arises from a current and existing problem in UNAD, and then, in stage two, the model is presented with the selection of variables to be considered for the design of the laboratory, such as; virtualization, geometric modeling and mathematical modeling. In a third stage the design process begins, and the resistor is characterized according to the performance

and all the interactions inside the virtual laboratory as the connection with the instruments available, and its behavior in a circuit analysis exercise. Finally, the last stage is the validation of the results [10].
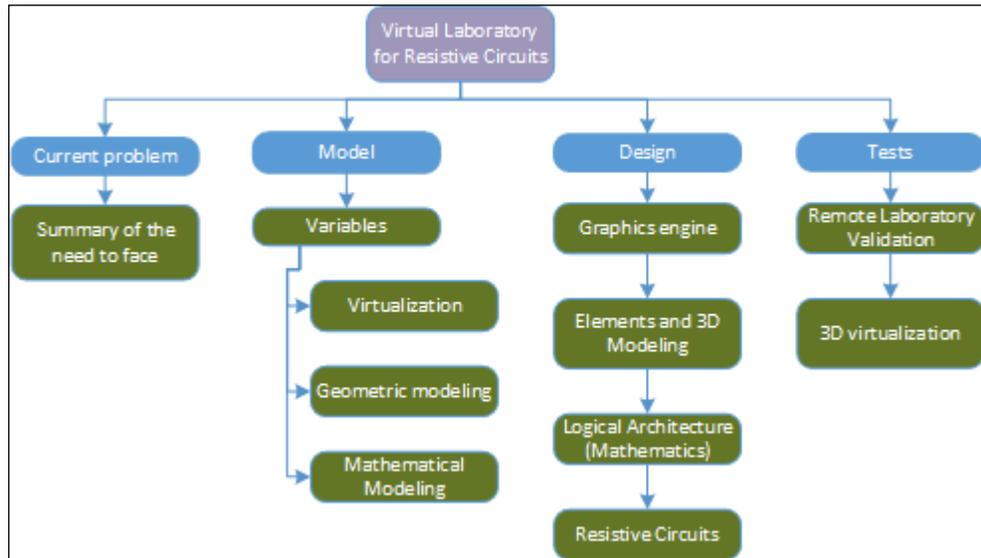

Figure 1, Proposed methodology for the design of a virtual laboratory in 3D

Thereafter, the proposed methodology allows to understand the general architecture of the research project and its variables, processes, and delimitations to be considered. In Figure 2, the general design scheme is presented using the selected graphics engine, therefore, for this process it's necessary to stablish that designers will have a learning curve in the use of the software, in order to obtain virtual Dome that is called: Virtual Laboratory for Circuit Analysis [11]–[13] .
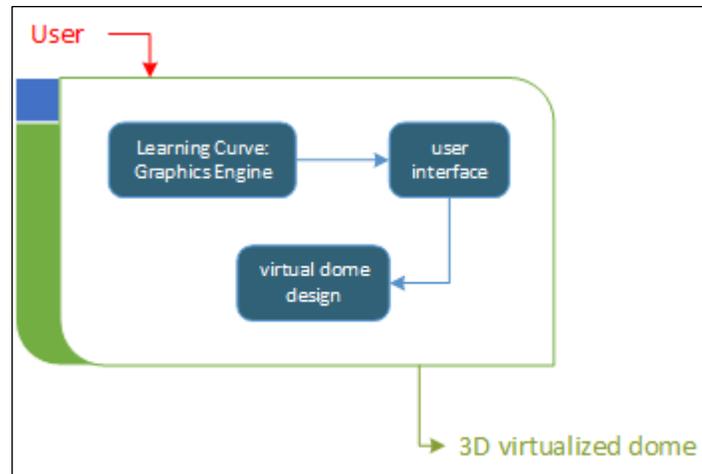
Figure 2. Proposed methodology for design and implementation using the graphics engine

The next stage is important for the development of the research project, the physical characteristics of the elements selected for the virtual laboratory are taken into account, in that sense those involved in the simulation of a circuit with resistive components are considered, for example, resistors, source, multimeter and Bakelites, therefore, for the development of named simulation elements that are incorporated into the virtual laboratory space called "3D virtualized dome" as can be seen in Figure 3, the process of creation and modeling of resistive circuit components is established according to its physical characteristics. With these products, the design of the interactions and the application of mathematical models are carried out, for example, in the design of the simulation of a resistive circuit, Ohm's law is taken into account, which allows obtaining results and analysis of the variation of varying currents and voltage in a circuit [14].
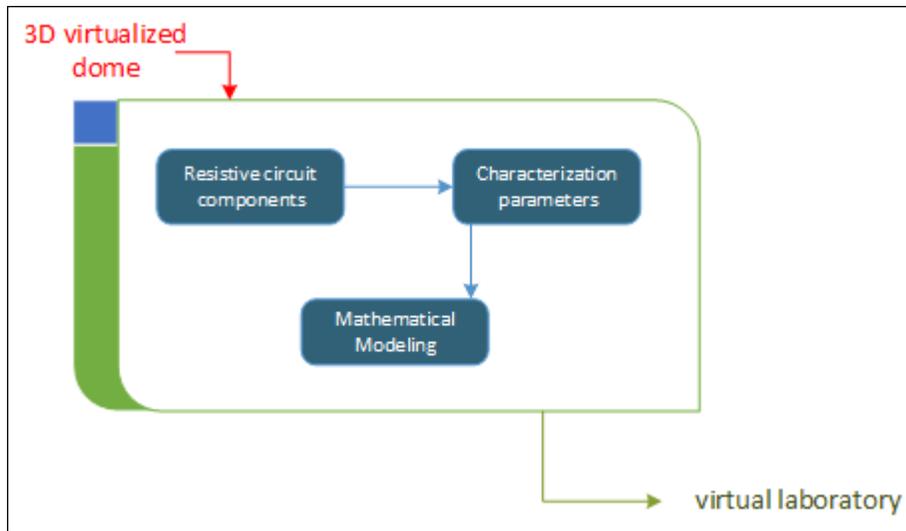
Figure 3. Proposed methodology for the design of the resistor

In the last stage for the development of the research project, the results analysis and testing processes are carried out, as can be seen in Figure 4, The virtual laboratory design is available with all the parts already created, such as modeling and design of the interactions and mathematical model. In the final stage the process of checking the elements that make up the laboratory and the resistive circuit to be simulated is carried out [15].
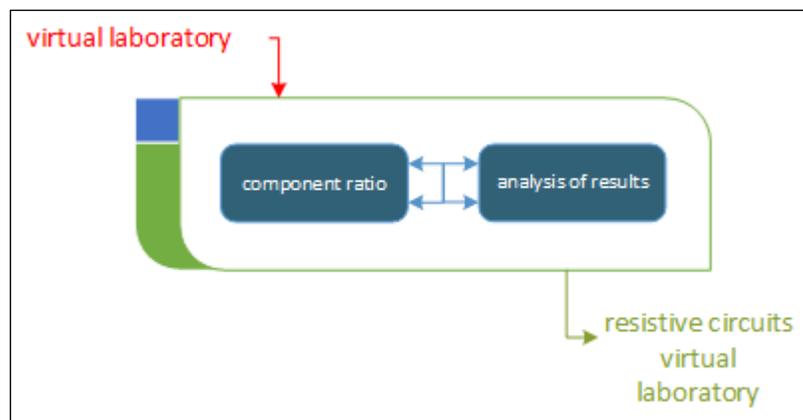

Figure 4. Proposed methodology for the analysis of results and possible improvements

The stages proposed as part of the methodological planning for the development of the resistor and the virtual laboratory includes some internal processes not shown in this document, but which are taken into account in each laboratory design process, therefore, develop of the models of the resistance and interactions may vary or become extended [16]–[18].

The process of creation and methodological planning for the project includes results that allow the dissemination of outcomes to the scientific and academic community [19].

2.2. Tools for creating the resistor in virtual laboratory

For the research project and creation of the resistor to be incorporated in virtual laboratory, it is necessary to consider some of the most important tools since there are several options on the market that allow the creation of scale models of physical devices and graphic engines, consequently, the tools used and the grounds for the selection of these are specified.

2.2.1. Geometric 3D modeling using Autodesk Maya

The design of resistors is carried out using Autodesk Maya software, where its graphic environment allows to model the structure of the device according to its shape of it with the tools to model objects in three dimensions, the version of the software used is the basic and trial version, considering the scope of the project in academic terms.

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2.2.2. Design of object interactions using a graphics engine: Unreal Engine

The behavior of the resistor with all the elements in virtual laboratory are programmed in Unreal

Engine - graphics engine software, which allows the creation of interactions using Blueprints programming, a technique that allows the development of movements, visualizations, connections and other characteristics that intervene in the actions of the virtual laboratory that allows to do a practical sesion [20]–[23].

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3. Results and Discussion

The results presented below shows the process of design a resistor to be incorporated in the virtual laboratory, but first it's important to design the spaces where the resistive circuits will be used. Once the device is designed, the research continues with all the other devices as the instrumentation elements, among others.

3.1. Modeling of devices and virtual laboratory

The geometric models in three dimensions created from the physical characteristics of their real counterpart are presented, and those are the main elements that intervene in the virtual laboratory [24], [25].

3.1.1. Circuit and resistor modeling

First, the modeling process for the development of the virtual laboratory are the circuits called "Bakelite" whose function is to determine if the circuit is Series or Parallel, and also the position of each of the resistors that make up the circuit, as shown in Figure 5 [22], [23].
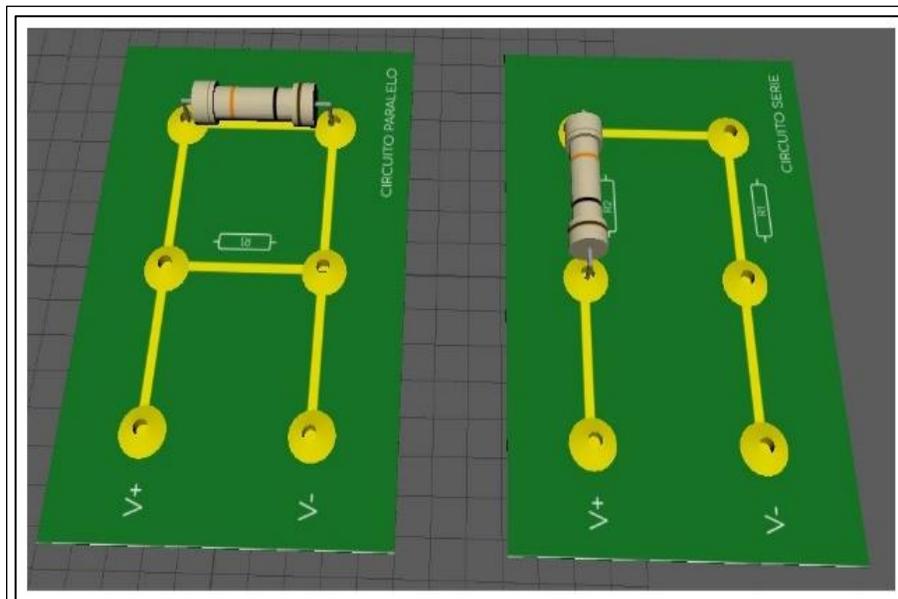
Figure 5. Bakelite design for parallel and series circuits with their resistors

For the design of these Bakelites together with the circuit resistances, it is textured from the geometric modeling program, with the purpose of making the design of the parallel and series circuits

3.1.2. Virtual laboratory modeling

The resistors in virtual laboratory need the simulation space and three-dimensional environment where they can interact as in a real laboratory, therefore, as mentioned above, the laboratory at the main campus of UNAD in Bogotá was recreated in geometric design software, as can be seen in Figure 6 [26]–[28].

Figure 6. Design of the virtual laboratory based on the real facilities of UNAD Bogotá

3.2. Modeling and interactions of the measurement elements and virtual laboratory using graphics engine

For the design process through the graphics engine used to render and obtain the characteristics of the designed elements, the Unreal Engine software is used, which has characteristics that allow more realistic designs due to the ability to apply shadows, light and textures, therefore, the elements designed for the laboratory are presented below.

3.2.1. Design of the interactions of measuring instruments and power supply

The instrumentation and power supply elements prepared in the three-dimensional design software are rendered, and the interactions are designed using the selected graphics engine. In Figure 7, the designs of the rendered elements are shown together with their functional tests [26], [29].

Figure 7. Result of the resistor designed with the instrumentation involved

Interactions are made for the designed instrumentation elements by blueprints programming, the interactive programming code that allows the measurement of the voltage in the circuit and generates the DC voltage, up to 30 volts to power the series circuits.

3.2.2. Circuit and resistor interaction design

The design of the interactions of circuits and resistors are rendered with the elements and texture called Bakelites, feature the characteristics of a series and parallel circuit, these can be seen in Figure 8.
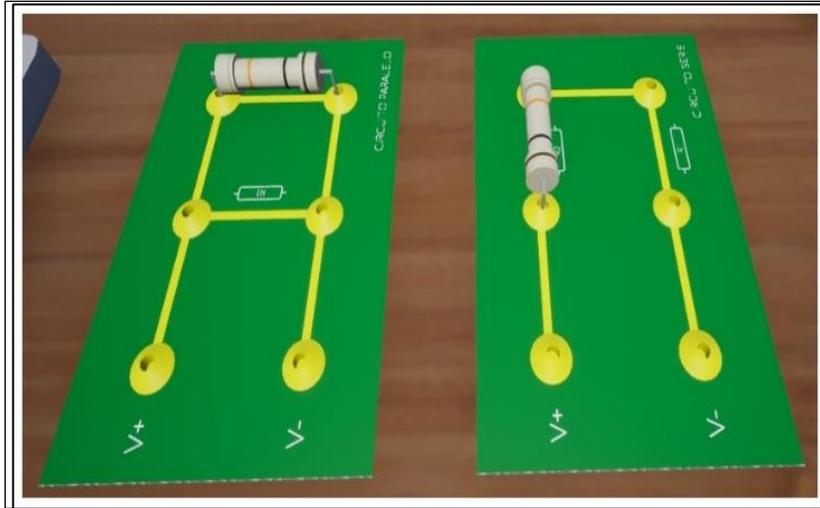
Figure 8. Design of the interactions of measuring instruments and power supply

The interactions programmed in the series and parallel circuits allow users to move the resistors in different positions, and the circuits implement the mathematical model through Ohm's law for the series and parallel cases. Therefore, users must connect the resistor to the correct point, otherwise the circuit won't work, and connect the power supply so that the circuit has the operating characteristics of a real circuit, and the voltage measurement of each of the points of the circuit can be made. For the measurement, the previously designed multimeter is used [30]–[32].

3.2.3. Design of virtual laboratory interactions

For the design of the interactions through blueprints for the virtual laboratory, the model created in the geometric modeling software is rendered, therefore, the design considers the real aspects of the real laboratory and the university facilities. As can be seen in Figure 9, on the left the real headquarters of the university, on the right the rendering and interactions of the laboratory created [17], [22], [32].

Figure 9. Design of the interactions of the virtual laboratory vs the real facilities of UNAD.

In the process of creating the interactions, the materials of the real building have been considerate so that approaches the user to a complete experience of the laboratory, so also, the programming of the opening and closing of doors is carried out as it works in real life.

3.3.   Final design of the virtual laboratory for the analysis of resistive circuits

As the last design process of the virtual laboratory, all the previously created processes are taken into consideration and are unified, resulting in the tool whose interface is presented in Figure 10.

Figure 10. Final design of the virtual laboratory together with the resistive circuits and the avatar

In the virtual laboratory designed, the measurement elements such as the multimeter and power supply are presented, the Bakelites are also presented with the circuit diagram in series and in parallel, the workspace for this case on a table with a computer which now has no interaction and the chair that accompanies the real experience, Furthermore, the avatar will be designed to interact with elements showing a *first person* perspective where the user just see the hands of the character to manipulate all devices available in virtual laboratory [22], [23]

4. Conclusions

The relevant conclusions of the research project are presented below:

- The design of resistors in 3D to be incorporated in virtual laboratories is possible due the powerful tools as Unreal Engine and MAYA, because allows to characterize the designs according to its behavior in real life. In that way, it's possible to reproduce a

circuit analysis practice in the same conditions.

- Despite the experience in the virtual laboratory, there are some limitations related with overheating problems, power generation dissipated in the form of heat, however, this will be considered in subsequent designs and subsequent phases.

- The interface in first-person has not been developed yet, however this is an important aspect to include in the design to improve the user experience.

- The interface for the user to interact with the elements in a first-person view has not yet been designed, therefore, it is expected to have it in the next phase of the project.

- The design of the virtual laboratory is presented so far in its first phase, therefore, there are still several aspects to improve and other elements to design together with the interactions and programming with blueprints, which will be developed in later phases.

- The project involves only resistive elements but in order to enhance the experience, elements like sensors to measure different magnitudes, capacitors, coils and others are considered to be incorporated to the virtual laboratory.

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References

[1] J. Buitrago-Molina, J. Carvajal-Guerrero, y C. Zapata-Castillo, "Plataforma virtual para el mando local y remoto de un brazo robótico de apoyo para la educación en ingeniería", *Tecno Lógicas*, vol. 17, núm. 32, 2014.

[2] N. J. Rodriguez García y I. C. Nieto Sánchez, "Consideraciones para el diseño de un sistema diagnóstico de frenos de disco en un vehículo particular", *Avances*, vol. 14, p. 76, 2017, doi: 10.18041/1794-4953/avances.1.1286.

[3] K. Takemata, A. Minamide, S. Nakamura, y N. Tanba, "Design of lifelong learning content using space education - Development of the mobile 3D (three dimensional) image projection system", en *Proceedings of the 2011 11th IEEE International Conference on Advanced Learning Technologies, ICALT 2011*, 2011, pp. 197–198, doi: 10.1109/ICALT.2011.63.

[4] W. Ridgewell, V. Kumar, O. Lin, y Kinshuk, "OpenSim virtual worlds as platform for enhanced learning concepts", en *Proceedings of the 2011 11th IEEE International Conference on Advanced Learning Technologies, ICALT 2011*, 2011, pp. 623–624, doi: 10.1109/ICALT.2011.192.

[5] H. N. Wu, X. M. Wang, L. K. Yu, T. Yuan, y S. G. Kuai, "Rendering a virtual light source to seem like a realistic light source in an electronic display: A critical band of luminance gradients for the perception of self-luminosity", *Displays*, vol. 59, pp. 44–52, sep. 2019, doi: 10.1016/j.displa.2019.07.001.

[6] J. Zhang, "Implementation and Optimization of Particle Effects based on Unreal Engine 4", en *Journal of Physics: Conference Series*, 2020, vol. 1575, núm. 1, doi: 10.1088/1742-6596/1575/1/012187.

[7] F. R. L. Viscaino y J. P. Sebastá, "LabView, entorno gráfico de programacióm", *Comput. Sci.*, p. 4, 2007 [Online]. Disponible en: https://www.semanticscholar.org/paper/LabView%2C-entorno-gráfico-de-programacióm-Vizcaíno-Sebastiá/bea05b9eb695a894760865bda606f0bdc64890ba#related-papers

[8] A. A. A. A. and R. L. T. CÁCERES, "Study of kinetic formation and the electrochemical behavior of polypyrrole films", *J. Chil. Chem. Soc*, 2009, doi: 10.4067/S0717-97072009000100004.

[9] Á. Arrieta A. y R. L. Tarazona C., "Sistema multicanal con instrumentación virtual para una lengua electrónica", *Ingeniare*, vol. 22, núm. 3, pp. 338–350, 2014, doi: 10.4067/S0718-33052014000300005.

[10] F. Salimi y F. Salimi, *A Systems Approach to Managing the Complexities of Process Industries - 1st Edition*. 2017 [Online]. Disponible en: https://www.elsevier.com/books/a-systems-approach-to-managing-the-complexities-of-process-industries/salimi/978-0-12-804213-7. [Consultado: 17-dic-2022]

[11] F. Banfi y C. M. Bolognesi, "Virtual Reality for Cultural Heritage: New Levels of Computer-Generated Simulation of a Unesco World Heritage Site", en *Springer Tracts in Civil Engineering*, Springer, 2021, pp. 47–64.

[12] L. E. Aparicio, L. Plazas-Nossa, y N. J. Rodriguez, "Design considerations for the

modulator and demodulator of the CUBESAT-UD earth station", *Informacion Tecnologica*, vol. 31, núm. 1. Centro de Informacion Tecnologica, pp. 245–252, 01-feb-2020 [Online]. Disponible en: http://dx.doi.org/10.4067/S0718-07642020000100245. [Consultado: 17-dic-2022]

[13] J. Alphonse y S. Diwakar, "Deploying a Web-based Electroencephalography Data Analysis Virtual Laboratory", en *Procedia Computer Science*, 2020, vol. 171, pp. 2420–2425, doi: 10.1016/j.procs.2020.04.261.

[14] A. Adán, S. Salamanca, y P. Merchán, "A hybrid humancomputer approach for recovering incomplete cultural heritage pieces", *Comput. Graph.*, vol. 36, núm. 1, pp. 1–15, 2012, doi: 10.1016/j.cag.2011.10.003.

[15] A. Candiago y L. T. Kawamoto Júnior, "Virtual multimedia environment to teach safety procedures in laboratories", en *Advanced Materials Research*, 2014, vol. 950, pp. 293–297, doi: 10.4028/www.scientific.net/AMR.950.293 [Online]. Disponible en: https://www.scientific.net/AMR.950.293. [Consultado: 17-dic-2022]

[16] D. X. Ramos Rivadeneira y J. A. Jiménez, "Entorno de Aprendizaje 3D no Inmersivo como apoyo al componente informático", *Av. Investig. en Ing.*, vol. 17, núm. 1, nov. 2019, doi: 10.18041/1794-4953/avances.2.5491. [Online]. Disponible en: https://doi.org/10.18041/1794-4953/avances.2.5491. [Consultado: 17-dic-2022]

[17] J. Ramírez *et al.*, "A virtual laboratory to support chemical reaction engineering courses using real-life problems and industrial software", *Educ. Chem. Eng.*, vol. 33, pp. 36–44, oct. 2020, doi: 10.1016/j.ece.2020.07.002.

[18] B. Jiménez Fernández-Palacios, D. Morabito, y F. Remondino, "Access to complex reality-based 3D models using virtual reality solutions", *J. Cult. Herit.*, vol. 23, pp. 40–48, ene. 2017, doi: 10.1016/j.culher.2016.09.003.

[19] F. Salimi y F. Salimi, "Modeling and Simulation", en *A Systems Approach to Managing the Complexities of Process Industries*, Elsevier, 2018, pp. 279–407 [Online]. Disponible en: https://linkinghub.elsevier.com/retrieve/pii/B9780128042137000050. [Consultado: 17-dic-2022]

[20] L. Herrera Mosquera, "Impact of Implementing a Virtual Learning Environment (VLE) in the EFL Classroom", *Íkala, Rev. Leng. y Cult.*, vol. 22, núm. 3, pp. 479–498, oct. 2017, doi: 10.17533/udea.ikala.v22n03a07. [Online]. Disponible en: https://revistas.udea.edu.co/index.php/ikala/article/view/325050. [Consultado: 17-dic-2022]

[21] E. Chu y L. Zaman, "Exploring alternatives with Unreal Engine's Blueprints Visual Scripting System", *Entertain. Comput.*, vol. 36, p. 100388, ene. 2021, doi: 10.1016/j.entcom.2020.100388.

[22] C. Kiourt, A. Koutsoudis, y G. Pavlidis, "DynaMus: A fully dynamic 3D virtual museum framework", *J. Cult. Herit.*, vol. 22, pp. 984–991, nov. 2016, doi: 10.1016/j.culher.2016.06.007.

[23] A. Zaldívar Colado, "Laboratorios reales versus laboratorios virtuales en las carreras de ciencias de la computación", *IE Rev. Investig. Educ. la REDIECH*, vol. 10, núm. 18, pp. 9–22, abr. 2019, doi: 10.33010/ie_rie_rediech.v10i18.454. [Online]. Disponible en: www.rediech.orghttp://www.rediech.org/ojs/2017/index.php/ie_rie_rediech/indexhttp://dx

.doi.org/10.33010/ie_rie_rediech.v10i18.454. [Consultado: 17-dic-2022]

[24] P. P. Jayaraman, X. Yang, A. Yavari, D. Georgakopoulos, y X. Yi, "Privacy preserving Internet of Things: From privacy techniques to a blueprint architecture and efficient implementation", *Futur. Gener. Comput. Syst.*, vol. 76, pp. 540–549, nov. 2017, doi: 10.1016/j.future.2017.03.001.

[25] B. Levchenko, A. Chukhray, y D. Chumachenko, "Development of Game Modules with Support for Synchronous Multiplayer Based on Unreal Engine 4 Using Artificial Intelligence Approach", en *Advances in Intelligent Systems and Computing*, 2020, vol. 1113 AISC, pp. 503–513, doi: 10.1007/978-3-030-37618-5_43.

[26] F. Sarghini, F. Erdogdu, y R. Accorsi, "Designing advanced food packaging systems and technologies through modeling and virtualization", en *Sustainable Food Supply Chains: Planning, Design, and Control through Interdisciplinary Methodologies*, Elsevier, 2019, pp. 83–104.

[27] J. D. Velosa-García, F. J. Castillo-García, E. Espíldora, y L. Cobo, "Requerimientos para laboratorios híbridos en Ingeniería de Manufactura", *DYNA*, vol. 84, núm. 203, pp. 65–74, dic. 2017, doi: 10.15446/dyna.v84n203.61495. [Online]. Disponible en: http://dx.doi.org/10.15446/dyna.v84n203.61495. [Consultado: 17-dic-2022]

[28] M. Á. Roque López, "Entendiendo la programación visual en el desarrollo de videojuegos", *Con A animación*, vol. 2019, núm. 9, p. 92, mar. 2019, doi: 10.4995/caa.2019.11336. [Online]. Disponible en: https://polipapers.upv.es/index.php/CAA/article/view/11336. [Consultado: 17-dic-2022]

[29] R. H. Chica Garcia, J. A., Rodriguez Aya, A. A., Figueredo Luna, J. A., & Polanco Contreras, "Sistema de monitoreo en tiempo real de gases CO, CO2, NOX y PM2,5 en la ciudad de Villavicencio.", *Memorias Expotech 2020*, vol. 1, pp. 1–7, oct. 2020, doi: 10.22490/25904779.4172. [Online]. Disponible en: https://hemeroteca.unad.edu.co/index.php/memorias/article/view/4172. [Consultado: 22-jun-2022]

[30] D. Ruiz Olaya y E. Franco Mejía, "Herramienta de emulación de sistemas dinámicos a través de internet", *Rev. Tecnura*, vol. 19, núm. 46, p. 103, nov. 2015, doi: 10.14483/udistrital.jour.tecnura.2015.4.a08. [Online]. Disponible en: http://revistas.udistrital.edu.co/ojs/index.php/Tecnura/issue/view/725DOI:http://dx.doi.org/10.14483/udistrital.jour.tecnura.2015.4.a08. [Consultado: 17-dic-2022]

[31] X. Shi, B. Chen, X. Tuo, Y. Gong, y J. Guo, "Study on performance characteristics of fused deposition modeling <scp>3D</scp> -printed composites by blending and lamination", *J. Appl. Polym. Sci.*, vol. 138, núm. 9, p. 32495, mar. 2021, doi: 10.1002/app.49926. [Online]. Disponible en: https://onlinelibrary.wiley.com/doi/10.1002/app.49926. [Consultado: 17-dic-2022]

[32] N. Kaur *et al.*, "A blueprint for electronic utilization of ambiguous molecular HLA typing data in organ allocation systems and virtual crossmatch", *Hum. Immunol.*, vol. 81, núm. 2–3, pp. 65–72, feb. 2020, doi: 10.1016/j.humimm.2020.01.007.