Digital Twins for Education: A Literature Review

João Eduardo Cosentino Bachmann, Ismar Frango Silveira, Valéria Farinazzo Martins

Programa de Pós-Graduação em Computação Aplicada – Faculdade de Computação e Informática - Universidade Presbiteriana Mackenzie
Rua da Consolação, 930, CEP 01302-907 – São Paulo - SP - Brazil

joao.cosentino@gmail.com, ismar.silveira@mackenzie.br, valeria.farinazzo@mackenzie.br

Abstract. *The evolution of Virtual Reality (VR) to Digital Twins (DT) represents a significant advancement in the field of immersive and interactive technologies, particularly when aiming to establish a connection between the physical and synthetically generated worlds. This connection provides conditions for simulation, prevention, and optimization of processes and systems in the real environment. The importance of this topic is based on various reasons. Opportunities are envisioned to apply DTs in several industrial sectors, like Education, especially in the areas of STEAM (Science, Technology, Engineering, Arts, and Mathematics). These applications can reduce costs and maximize innovation opportunities in the teaching-learning processes, supporting the testing of scenarios and strategies in a safe virtual environment that correlates with real-world implementation. Thus, this paper presents a literature review on the applications of DT in Education, offering a contemporary panorama and pointing out some directions for future research.*

Keywords. *Education, Digital Twins, Simulation, Mixed Reality*

1. Introduction

The Covid-19 pandemic forced teachers and educational managers to rapidly adopt technological solutions to overcome the limitations of social isolation, accelerating the adoption of technological innovations [Araujo et al., 2020]. While this adoption previously faced resistance and progressed slowly, the pandemic led to a more accelerated adoption, yet it also highlighted the already existing digital divide [Souza et al. 2023]. Considering these recent events, the current educational landscape seems more receptive to the adoption of new technologies.

One of these new technologies that has recently emerged in other fields of knowledge is what is conventionally called Digital Twins (DT). DT and Simulations are often considered similar concepts. However, DTs are virtual representations of physical objects or systems that are continuously updated with real-time data, allowing for constant monitoring and optimization. In contrast, simulation creates models that mimic the behavior of systems under specific conditions, usually to test scenarios without a continuous connection to the physical world. Therefore, while DTs reflect the current state of the system, simulations are static and used to explore predefined hypotheses [Siqueira et al., 2024].

Initially used in the aerospace industry by NASA (2010), they now appear as a technological innovation applicable to various other areas, such as Education. DT, which now incorporates IoT and big data analysis, can create realistic, real-time and interactive

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simulations, allowing for the prediction of future scenarios and optimization of educational processes, potentially revolutionizing teaching. Some applications of Digital Twins in the field of Education are listed below:

- **Science, Technology, Engineering, Arts, and Mathematics (STEAM)**: Simulations of scientific experiments, process simulations, modeling of complex systems, digital art, and visualization of abstract concepts, using real-time data and interacting with physical counterparts of a DT;
- **Healthcare Education**: Training in medical, veterinary, nursing, and dental procedures, including surgical training, as well as simulation of human and animal anatomy and physiology, in connection with real bodies and parts, surgical instruments and hospital equipment;
- **Architecture and Civil Engineering Education**: Learning experiences in these fields could strongly benefit from real-time data-based virtual modeling of buildings and infrastructure, integration with Building Information Modeling (BIM) systems, project simulation, and analysis of structural, soil, and thermal comfort factors, allowing hypothesis tests and experimentations;
- **Technical Training**: Workforce training processes could have a significant improvement on efficiency and security, using DT for simulation of equipment maintenance, industrial operations, and technical procedures — especially high-risk ones such as maintenance of power plants, vehicles, and electromechanical equipment.

Given that this is still an emerging field, it is necessary to analyze the already experimented use cases to project future applications in the educational domain. Considering this, the objective of this article is to present a Literature Review regarding the applications of Digital Twins in Education, providing an overview of the current state and exploring potential uses and research challenges in the area.

The article is structured as follows. Section 2 presents the fundamental concepts of Digital Twins, including a classification of different types of Digital Twins and differentiating the concepts of Digital Twins and Simulation in Education. Section 3 outlines various areas of application of Digital Twins in the educational context, such as virtual campuses, virtual laboratories, healthcare training, and professional training. Section 4 discusses the research challenges in the field of Digital Twins in Education. Finally, Section 5 presents the conclusions and future perspectives on the use of Digital Twins in Education.

2. Theoretical Background

A recent technological innovation primarily utilized in industry and manufacturing is now being explored for application in education: Digital Twins. Although the term has garnered increased research and applications in recent years, it originated in the 2010s with NASA (2012). Initially, DT were defined as multiphysical and multiscale simulations of a vehicle or system using the best physical models, sensors, and flight history to replicate the life of its real counterpart. This concept was closely tied to the aerospace industry [Van der Valk et al., 2020; Rosen et al., 2015].

A broader definition [Zacher 2020], while still focused on manufacturing, describes a DT as a software model serving as a prototype for a product, employed at all stages of industrial production to compare the current state with the model and correct discrepancies. This approach creates a virtual representation of the real world, enabling continuous communication between both realms throughout the production process.

DT has the potential to create realistic and interactive simulations that enable students to explore, test, and understand complex concepts. Their use is particularly anticipated in science, technology, engineering, arts, and mathematics (STEAM). However, the implementation of DT in education faces several barriers, particularly in developing countries like Brazil - and the entire Latin America, whose digital gap [Tomczyk et al., 2019] is well-known. These barriers include a lack of infrastructure, absence of supportive public policies, and the high initial cost and complexity of implementation. Furthermore, issues of data privacy and security must be rigorously addressed in compliance with the data protection laws of respective countries.

2.1. Digital Twins: a Taxonomy and the evolution from VR systems

Currently, there is no universally accepted definition of the term "Digital Twin": in the educational field, the definition provided by Zacher (2020), is probably the most widely accepted: "A digital twin is a simulated and visualized software model of an original system, which looks exactly like the original system and operates in real-time so that its operations are synchronized with the original system." However, several considerations must be made: not all DT requires VR/MR (Virtual Reality / Mixed Reality); the similarity to the original system can be total or partial; and synchronization is not always bidirectional and real-time. Thus, a taxonomy is presented in Figure 1, based on the previous work of Van der Valk et al. (2020) and Siqueira et al. (2024).

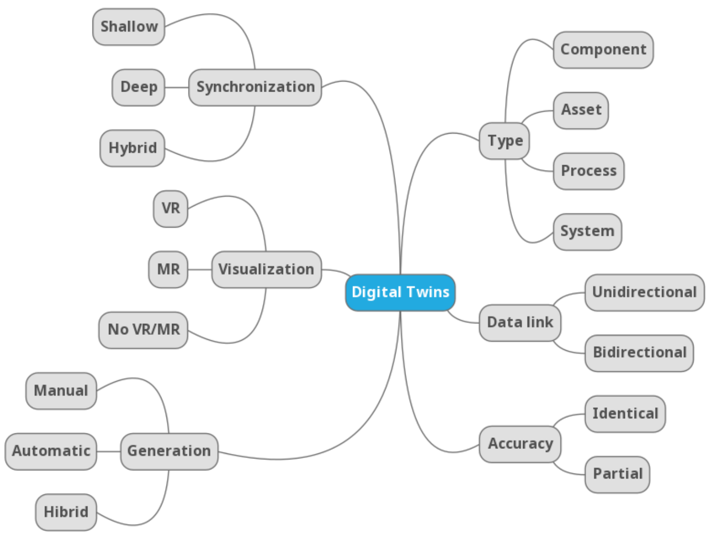

Figure 1. A taxonomy for Digital Twins – source: [Siqueira et al., 2024]

The taxonomy, better presented in Siqueira et al. (2024), can be interpreted as follows. Regarding the DT type, they could be the counterparts of components or entire assets (objects); but since they can also be digital counterparts of processes or systems, extending the original definition of DT, they may not require VR or MR visualizations or interactions. Talking about Data Link, an unidirectional link refers to data flowing from one twin, whilst a bidirectional link involves real-time data exchange between both models. The Accuracy of DT could be total, when they are accurate copies of their physical counterparts; however, partial accuracy is sometimes sufficient. Regarding the models' generation, they can be developed manually, but semi-automatized modeling processes are already in use, going to an Artificial Intelligence - based automated generation. About visualization, it can be done through VR/MR environments, but in some cases, no VR/MR visualization is required. On the other hand, synchronization refers to the fact of changes in physical or virtual environments being mirrored (deep twins) or no (shallow twins) in their counterparts.

It is important to understand DT as an evolution of realistic VR and MR environments, but not in a simple way. The authors Siqueira et al (2024) present a continuum that explicits the most important technological advances that had influence on this evolution, as depicted by Figure 2.

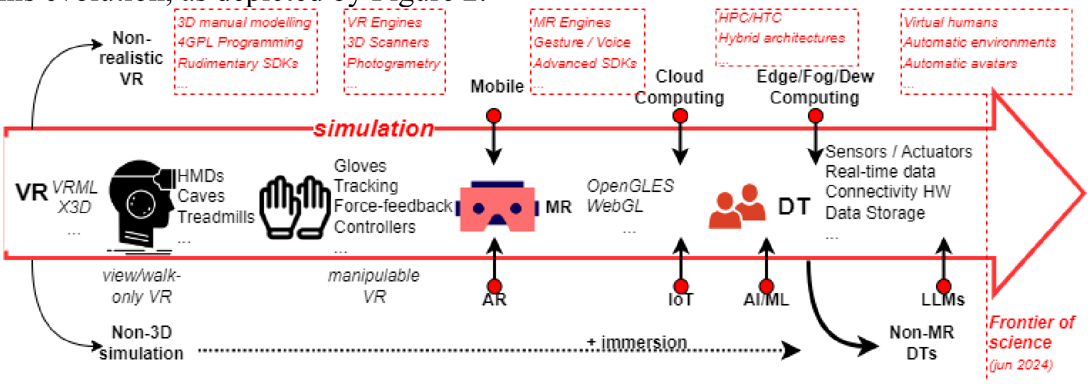

Figure 2. The VR-DT Continuum – source: [Siqueira et al., 2024]

As seen in Figure 2, from the very beginning of VR, when not-so realistic virtual worlds were possible to be visited through walkthroughs (at that time, manipulation tools were still in development) using cumbersome devices, like heavy HMD Head-Mounted Displays) or in VR Caves, until the advent of DT, a considerable amount of technological innovations were required.

The continuum of VR to DT illustrates significant technological evolution, impacting data processing, storage, transmission, and visualization. Initially, VR in the late 1980s and 1990s involved basic devices like HMDs and treadmills, focusing on walkthroughs in 3D environments. Early VR was limited by high costs and technological constraints. The second phase saw advanced manipulation devices like haptic gloves and 3D position tracking, enhancing immersion. The advent of Augmented Reality (AR) and MR further expanded possibilities, integrating VR with mobile computing and gesture recognition. The latest phase involves DT, driven by advancements in connectivity, IoT, AI, and automatic 3D content generation. These innovations facilitate the creation of virtual counterparts for real-world elements, with potential significant impacts on diverse areas, including new possibilities for DT-based educational methods and tools. For instance, the integration of DT with Multimodal Learning Analytics (MLA) allows real-time data-based experimentation in educational settings, enhancing the learning experience.

3. Related Work

To have a better holistic view of the current state of the art of DT in education, an integrative review was performed in order to identify what is the overall usage of DTs for educational purposes within universities, either as a business tool or as a part of an individual program, course or discipline. Also, it is being considered educational and technical training across different industries and businesses. The material researched was sourced from Journals, Articles, Conference Papers and Books chapters, indexed with Scopus and MDPI databases. The selection criteria were: year of publication (specially after COVID-19), type of study as to how DT are being addressed, as the intention here is to have an overview of the actual level of application of this technology. Works and studies that used the DT concept as a part of disciplines of university courses, were also considered.

Due to its comprehensive nature, when discussing the development and application of the Digital Twins concept, the literature presents a wide array of works and themes where its usage is adopted. In education, this diversity is evident, ranging from highly specific applications such as the use of DT to modernize engineering courses, thereby enhancing student engagement in project development and management disciplines, as demonstrated by Nikolaev et al. (2018), to more general scenarios where DT serve as tools for social engagement through virtual classrooms or laboratories [Palmer et al., 2022] or even for simulating processes or systems, sometimes without VR/MR visualization. To better explore these diverse applications, for a clearer and deeper understanding of their nuances, they have been subdivided in the upcoming topics.

3.1 Digital Twins in Science, Technology, Engineering, Arts, and Mathematics

The adoption of the Digital Twins concept by universities assumes several roles, such as: virtualization of university environments (virtual campi); improvement in the learning process; technical training; enhancing student readiness for the market; gamification of disciplines; and cost reduction in equipment and laboratories.

Among the uses of the DT concept by universities, the virtual representation of technical environments or high-cost equipment is among the most popular. Among the gains from this adoption are the enhancement of the student experience and preparation for the current market, as well as benefits related to university costs, particularly in terms of laboratory construction and equipment purchase [Zacher, 2020]. In the specific case of the application from Zacher (2020), there was a 26% reduction in costs for a laboratory in the Master's program in Applied Sciences at the University of Darmstadt. In Marthur et al. (2023), the development of a reconfigurable Digital Twin is presented. The common basis consists of the communication infrastructure between entities and a historical database. The project was carried out at the Singapore University of Technology and Design. The Digital Twin proved to be highly valuable for the university's R&D center, where it is used for various research, educational, and training activities.

In universities and schools, gamification is another approach benefiting from the application of Digital Twins. Gamification can be understood as the use of game elements in real-life contexts. The use of these elements—narrative, feedback, cooperation, scores, etc.—aims to increase individuals' motivation [Costa et al., 2018]. In Lee et al. (2023), a university in South Korea is cited as a use case where Digital Twins are used to gamify the teaching of Mathematics for students from less related areas to the discipline. The high complexity and interdisciplinary nature required for the creation of a Digital Twin were used in Hagedorn et al. (2023) as a basis for developing project management skills. Digital Twins are also used as a way to assess students' effort and motivation in engineering education disciplines. In their research, Liljaniemi and Paavilainen (2020) sought to develop a conceptual course for including the Digital Twin theme in a Control

Systems Simulation discipline. Students are responsible for developing a Digital Twin of a PLC throughout the course. It was observed that including the theme can generate increased motivation, as well as accountability for the student's own learning. Within Robotics University's education, Digital Twins are being used to virtualize Training Centers for trainees and students. Due to the challenges of having a sufficient, in size and in adaptability laboratory to handle the capacity of training and researching for students and industrial partners, the use of Digital Twins to digitalize a Robotic Industrial Arm laboratory was performed by Erdei et al. (2022). The aim of the study was to measure the gap from using a real laboratory against digital ones. The study was performed with students from different disciplines and at different levels of knowledge regarding robotic and automation technology in the University of Debrecen Faculty of Engineering as shown in Figure 3.

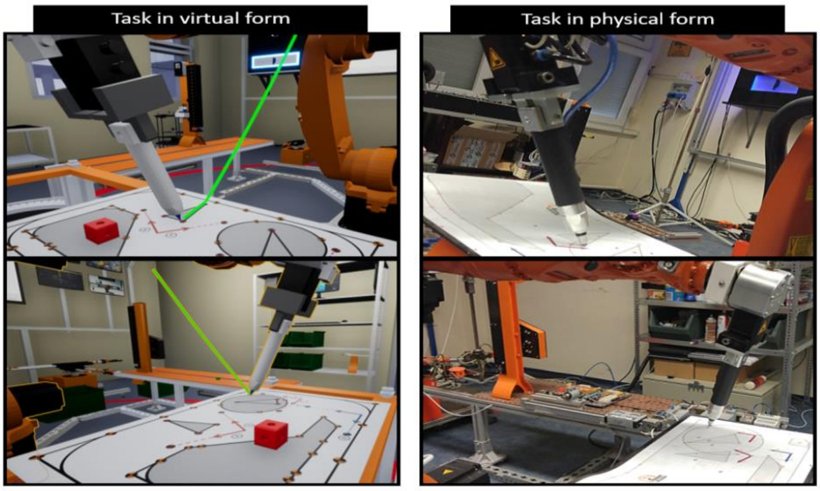

Figure 3. Comparison between Virtual (DT) and Physical form for students training on an Industrial Robotic Arm system – source: [Erdei et al., 2022]

To test the effectiveness of the Virtual training with DT, students were divided into two groups, one of them having the opportunity to use the Digital Twin created and the other only using paperwork. After performing the tasks shown in Fig. 3, students that had the opportunity to study using the DT, were more prepared and more knowledgeable, in contrast to the ones only using paperwork and documents who had much more difficulty performing the tasks [Erdei et al., 2022].

3.2 Digital Twins in Health Education

The use of DT in Health Education appears to still be somewhat incipient, as demonstrated by the works found. Drummond and Gonsard (2024) conducted a scoping review that analyzed definitions and characteristics of patient Digital Twins for clinical use. They identified 86 articles, nearly all in preclinical phases. In this context, a Digital Twin was defined as "a visualizable digital replica of a patient, organ, or biological system containing specific multidimensional patient information." The authors classified Digital Twins into two types: simulation and monitoring, with applications ranging from personalized predictions to optimizing continuous care. Johnson et al. (2023) envision the use of DT in Health Education. In this context, the authors point out that Health Digital Twins (HDTs) can revolutionize personalized medical treatments by combining research knowledge with the unique patient history and physiology. Initial examples include simulations of the heart and brain, but the field's evolution should encompass cellular models, microbiota, and patient slices on multidisciplinary platforms. Thus, they predict that HDTs will cover all medical disciplines and the entire patient journey, improving medical practices, precision medicine, and surgery, as well as increasing patient autonomy for better overall health. In the work of Attaran and Celik (2023), the authors mention that Virtual Reality (VR) technology has had the potential for decades to be used in medical training, complementing and enhancing traditional health education. Thus, AI-enabled DTs, using the power of Virtual and Augmented Reality, can facilitate training and education for healthcare professionals. For example, three-dimensional models can be used for the study of medical anatomy and surgical procedures to promote interactive learning and minimize the use of cadavers. In this way, Medical Schools can use Digital Twin solutions to teach surgical techniques using simulation.

According to Iqbal, Krauthammer, and Biller-Andorno (2022), DTs can assist in various medical functions and in all stages of the disease lifecycle: pre-disease management, disease management, and post-disease management. Thus, the authors point out the use of Digital Twins in the contexts of screening and prevention, diagnosis, prognosis, treatment and relief, prediction of intervention effects, and disease monitoring. However, the authors point out several ethical challenges with the use of DT in the Medical area, namely:

- **Equity in Access to Technology**: The shortage of medical and IT professionals can increase competition, benefiting wealthy countries and widening inequalities. Reimbursement policies can accentuate differences in health outcomes based on ability to pay;
- **Complexity, Legal Responsibility, and Ownership**: Allocating responsibility is still an open issue, as the complexity of Digital Twins can make it difficult to clearly define responsibilities. Responsibility may lie with companies developing Digital Twins, questioning who owns the specific patient model and how to ensure the safety and effectiveness of these models;
- **Autonomy and Nonmaleficence**: DTs can create a false sense of security and excessive dependence, threatening the autonomy of patients and healthcare professionals, as medical decisions may be influenced by DT recommendations;
- **Privacy**: Maximum Potential for Data and DT Model Abuse: Integrating multiple data sources and analyzing medical functions have significant financial value for legitimate and illegitimate stakeholders. The risk of hackers and abuse of sensitive data is significant, making the protection of Digital Twins critical and questioning potential benefits versus risks.

3.3 Digital Twins in AEC (Architecture, Engineering, and Construction) Teaching

A common finding in the papers reviewed is that the concept of Digital Twin is still in the prototype phase in the AEC sector compared to other industries, as real applications are rare [Pregnolato et al., 2022]. Much of this is due to the lack of protocols and standards that would serve as a guide. To address this issue, academia and industry have been working to define processes for developing a Digital Twin, especially for legacy infrastructures, which are less likely to have support for the necessary technologies to adapt to a DT implementation [Pregnolato et al., 2022]. In the UK, major AEC consulting firms (e.g., Arup, Mott MacDonald) have been working with the CDBB (Center for Digital Built Britain) and universities (e.g., Cambridge University's Institute for

Manufacturing) to align their agendas with the future vision for Digital Twins. Some metrics have already been defined in the report by Arup (2019), such as autonomy, intelligence, learning, and fidelity. Each of these is evaluated on a scale of 1 to 5 regarding the maturity level of the Digital Twin implementation. In addition to the aforementioned aspects, the multidisciplinarity, dynamism, and high complexity present in infrastructure and construction projects have attracted even more the construction industry's attention towards implementing Digital Twins in their projects [Dai and Brell-Çokcan, 2022] as shown in Figure 4.

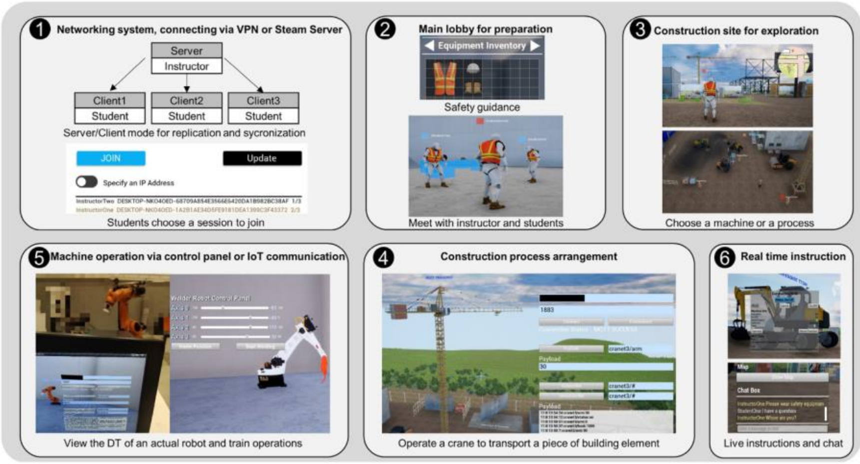

Figure 4. Core functions of a DT based Multiplayer game used in construction teaching. – source: [Dai and Brell-Çokan, 2022]

Although still in its infancy in this field, the concept of Digital Twin and the surrounding technologies are gaining more space in university education, Calveti et al. (2024) discusses the current need for civil engineers to master concepts related to technology and IT infrastructure and project management. As an example in Kangisser et al. (2022), the concept of Digital Twins helps university students in Civil Engineering, Civil Construction, and Architecture courses at the Georgia Institute of Technology understand what is known as Construction 4.0. This is defined by Smit, J. et al. (2016) as the organization of production processes based on technology and devices that communicate autonomously. Following this line, Calveti et al. (2024), talks about the importance of updating curricula in Civil Engineering courses, and how integrating the concept of Digital Twins into the curriculum can help students in course engagement, self development and readiness for the Construction 4.0 market, keeping up with the industry's technological revolutions. In fact, the work of Dai and Brell-Çokcan (2022), saw an increase in motivation and learning interest of the students through the usage of the Unreal game engine to develop a DT of a construction site in Aachen West, which is a campus-based living lab.

3.4 Digital Twins - R&D and Technical Training in Automotive, Robotics, and Energy Industries

The concept of Digital Twins is already well known in the automotive sector, where major manufacturers use them as a faithful virtual representation of the vehicle's mechanical and aerodynamic parts. However, with the advancement of autonomous driving technologies, Digital Twins have assumed an even more important role for the sector, specifically in R&D for vehicle communication and autonomous vehicle training [Samak et al., 2023]. This further encourages the inclusion of Digital Twins in the training of professionals working in this area. In the energy industry, specifically in the area of Smart Grids (SGs), due to the high cost related to developing test-beds capable of supporting real attacks and adapting to different scenarios and applications, creating a Digital Twin is of utmost importance to facilitate training for various types of cyber attacks and conducting research [Kandasamy et al., 2020]. In his work [Kandasamy et al., 2020] developed a Digital Twin of an Industrial Control System plant, on the size of a micro grid, despite the differences between the Digital Twin and the physical test-bed due to constraints, the project made it possible for students, researchers and training operators to perform their assessment on threats of attacks into the components of the grid, vulnerabilities of the system as well as performing rapid deployments and prototyping.

Figure 5 shows an example of DT for workforce training in a Brazilian electrical company, showing an avatar of a worker manipulating high-risk electrical equipment, having access to real-time information about the asset.

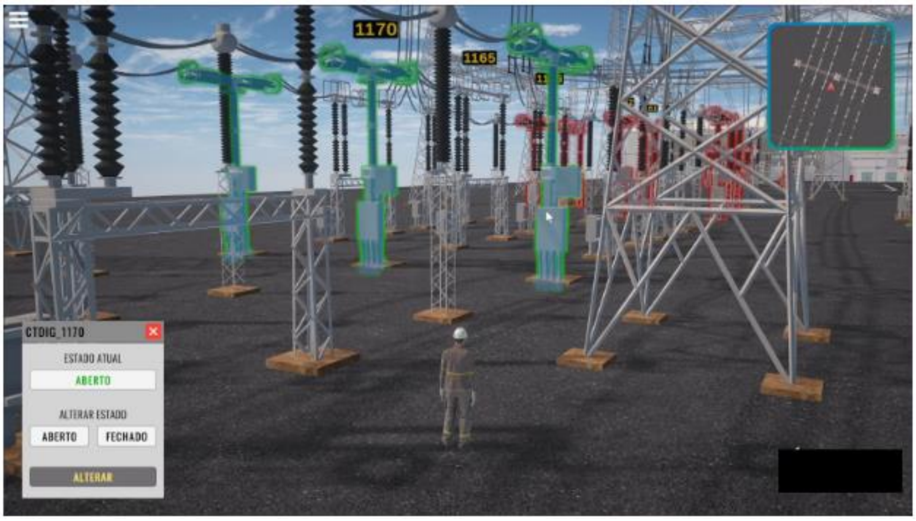

Figure 5. A DT application for training on electrical system with real-time information from the real substation (in Portuguese) – source: [Siqueira et al., 2024]

4. Research Challenges

As a nascent technology in Education, DTs face barriers to effective implementation, particularly in developing or underdeveloped countries. Key challenges include:

- **Technical Complexity**: Implementing and maintaining Digital Twins requires advanced technological infrastructure, which involves:
    - Developing realistic 3D models to represent complex components and objects, or mathematical models for processes and systems;
    - High-speed, secure networks capable of synchronizing Digital Twins with their real counterparts and transmitting large data volumes in real time;
    - Storing vast amounts of data and their models;
    - Real-time parallel and distributed processing capabilities;
    - Sensing and actuating elements in real-world components;
    - Skilled teams to implement, manage, and update all system components.

- **Initial Cost**: The development of Digital Twins often requires significant initial investment due to the aforementioned technical complexity. Additionally, ongoing maintenance costs are substantial;
- **Security and Privacy**: Robust cybersecurity measures are essential to comply with data protection laws in each country, given the extensive data collection and analysis involved in Digital Twins;
- **Integration with Existing Systems**: Integrating new systems with existing ones is generally complex. In the educational context, this complexity is heightened by the need for a paradigm shift. Integration considerations must encompass administrative systems, existing Virtual Learning Environments, and the limitations and possibilities of integrating with Digital Twins;
- **Digital Divide**: Inequities in technology access can limit the reach of Digital Twin solutions, particularly in developing or underdeveloped countries, or regions and communities with high social vulnerability, which is a big issue in Latin American countries [Souza et al., 2023];
- **Accessibility**: Given the various media involved in Digital Twin solutions, the limitations of students with physical and cognitive disabilities must be considered. Lessons learned in other educational contexts, regarding content creation [Eliseo et al., 2023], could be helpful.

Literature review suggests pathways to mitigate these challenges. Regarding technical complexity, research opportunities include:

- Automating or semi-automating the generation of 3D models for objects and environments using Artificial Intelligence techniques such as Large Language Models (LLM), 3D Generative Adversarial Networks (GAN), photogrammetry, and other image-based techniques, and advanced Computer Vision technique , or a combination of these methods. For Digital Twins based on 3D models, these solutions minimize modeling effort, time, and cost [Luhmann et al., 2023; Song et al., 2023; Hong, 2023; Hu et al., 2024];
- More humanistic conversational agents could improve the usability of DT. Research in Virtual Humans [Zalake et al., 2020] shows that users can experience a more engaging, efficient, and user-friendly interface that leverages the full potential of the technology;
- Enhancing devices, techniques, and architectures for storage, connectivity, and processing is essential for effective Digital Twin implementation. Beyond Cloud Computing, solutions like Edge Computing, Fog Computing, and Dew Computing [Ageed et al., 2021] should be considered;
- For sensors and actuators in the IoT context integrated with Digital Twins in Education, further research is needed. Some important advances in this aspect have been reached in the field of Multimodal Learning Analytics [Ochoa et al., 2022];
- Regarding the digital divide, effective public policies and research to make storage, network, and connectivity technologies more affordable and widespread are crucial. But, more than the infrastructural elements, teacher training is a crucial part of the process. For instance, OLPC (One Laptop Per Child)-related projects [Maciel; Passerino & Bez, 2011; Fabris & Finco, 2012] were focused more on the distribution of the laptops rather than on the accompanying teacher training and support. This lack of emphasis on teacher preparation often resulted in

underutilization of the laptops and missed opportunities to enhance learning outcomes. An important exception has been Ceibal in Uruguay [Pittaluga & Rivoir, 2012], which emphasizes teacher training and content generation, offering reasonable directions for reducing the digital divide compared to merely providing equipment. included comprehensive teacher training and ongoing support, which contributed to its relative success. Teachers were provided with professional development to integrate the technology into their curriculum - the same preoccupation must be carried out when adoption DT solutions in Education;

- For accessibility, despite numerous initiatives related to assistive technologies and educational models for inclusion, such as Universal Design for Learning (UDL) [Rose & Meyer, 2002], more research efforts are needed to enhance these technologies and restructure models to support inclusion in complex interactions with DTs.

5. Conclusions and Further Work

This article presents a literature review on Digital Twins in the educational field, highlighting various application scenarios: Science, Technology, Engineering, Arts, and Mathematics (STEAM), Healthcare Education, Architecture and Civil Engineering Education, Technical Training, and Management, Economy and Business. The focus of this article also includes proposing and explaining a taxonomy that involves the inherent concepts of DT, as well as an overview of the evolution from VR to DT in terms of technologies, methodologies, equipment, tools, and so on. Additionally, it discusses the continuous evolution from VR to DT in terms of technologies, tools, languages, etc., which are intrinsically linked to the educational field.

In higher education, we discussed the adoption of DT by universities in various fields, including virtualizing campus environments, improving learning processes, and reducing costs for equipment and laboratories. We also address gamification as another approach benefiting from DT in education, using gamification elements to increase motivation. In robotics education, DTs virtualize training centers, with students using DTs demonstrating better preparedness and knowledge compared to traditional methods. This underscores the effectiveness of DTs in enhancing educational outcomes across various courses.

The use of DT in Health Education is still emerging, with key applications identified in simulation and monitoring of patients, organs, or biological systems. DTs have the potential to revolutionize personalized medical treatments by integrating research knowledge with patient-specific data, extending to all medical courses. Additionally, AI-enabled DTs using VR and AR enhance interactive learning in medical training.

In the Architecture, Engineering, and Construction (AEC) sector, the concept of DT is still in the prototype phase, with few real applications. This is largely due to the lack of protocols and standards. Efforts are being made to define development processes, particularly for legacy infrastructures.

In the industry area, the concept of DT is widely used in the automotive sector for representing vehicles' mechanical and aerodynamic parts. With advancements in autonomous driving, DTs play a crucial role in vehicle communication and autonomous vehicle training [Samak et al., 2023]. This has expanded DTs' use in professional training.

In the energy industry, particularly Smart Grids (SGs), DTs are vital for training and research due to the high cost of real test-beds. Kandasamy et al. (2020) developed a DT of an Industrial Control System plant, enabling assessments of grid vulnerabilities, rapid deployments, and prototyping.

Further research is required to fully explore the potential of DT in various domains, and in Education additional efforts must be made by researchers, educational institutions, and companies, together with public policies focused on teacher training and on reduction of digital gap, so that, once again, this field does not fall behind in technological innovations.

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