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ORIGINAL

Using Digital Twin Technology to Conduct Dynamic Simulation of Industry-Education Integration

Uso de la tecnología de gemelos digitales para realizar una simulación dinámica de la integración de la industria y la educación

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ABSTRACT

The high accident rate in the construction industry has a major impact on how well projects turn out. Despite substantial investments in safety planning and supervision, there has been a marked increase in the construction industry's accident rate compared to other sectors. Serious games based on VR have recently been used in the study, suggesting that workers are now more safety conscious. However, these situations need many resources to create and are not always realistic. Hence this paper, Digital Twin-based Construction Safety Training Framework (DT-CSTF) with Artificial Intelligence (AI), has been proposed to monitor employees' emotional, mental, and physical well-being in real-time. The report sheds light on the significance of DT technology and its function in Industry 5.0. Using the Unity game engine, the proposed DT-CSTF creates a virtual reality-based training environment (VRTE) prototype that incorporates BIM, construction timetables, and safety requirements. Following this, the suggested structure enables gathering user data about risks and providing tailored feedback. Automated virtual reality game training scenarios are created using data given by digital twins on project intent, project status, safety requirements, and history. Both improved digital twins and periodic construction safety monitoring are anticipated to reap the benefits of dynamic virtual reality training. The proposed management system offers effectiveness of VR-based security training, cost-benefit analysis, monitoring,employee behaviour, safety education values are obtained by the ratio of 96,90 %, 98,33 %, 99,25 %, 95,91 %, 98,66 % respectively.

Keywords: Digital Twin (DT); Virtual Reality (VR); Workers Safety; Artificial Intelligence (AI); Education.

RESUMEN

La alta tasa de accidentes en la industria de la construcción tiene un impacto importante en el resultado de los proyectos. A pesar de importantes inversiones en planificación y supervisión de la seguridad, ha habido un marcado aumento en la tasa de accidentes de la industria de la construcción en comparación con otros sectores. Recientemente se han utilizado en el estudio juegos serios basados en realidad virtual, lo que sugiere que los trabajadores ahora son más conscientes de la seguridad. Sin embargo, estas situaciones necesitan muchos recursos para crearse y no siempre son realistas. Por lo tanto, se ha propuesto este documento, Marco de capacitación en seguridad en la construcción basado en gemelos digitales (DT-CSTF) con inteligencia artificial (IA), para monitorear el bienestar emocional, mental y físico de los empleados en tiempo real. El informe arroja luz sobre la importancia de la tecnología DT y su función en la Industria 5.0. Utilizando el motor de juego Unity, el DT-CSTF propuesto crea un prototipo de entorno de capacitación basado en realidad virtual (VRTE) que incorpora BIM, cronogramas de construcción y requisitos de seguridad. A continuación, la estructura sugerida permite recopilar datos de los usuarios sobre los riesgos y proporcionar comentarios personalizados. Los escenarios de capacitación de juegos de realidad virtual automatizados se crean utilizando datos proporcionados por gemelos digitales sobre la intención del proyecto, el estado del proyecto, los requisitos de seguridad y el historial. Se prevé que tanto los gemelos digitales mejorados como el monitoreo periódico de la seguridad de la construcción aprovecharán los beneficios de la capacitación dinámica en realidad virtual. El sistema de gestión propuesto ofrece efectividad de la capacitación en seguridad basada en realidad virtual, análisis de costo-beneficio, monitoreo, comportamiento de los empleados y valores de educación en seguridad que se obtienen en una proporción de 96,90 %, 98,33 %, 99,25 %, 95,91 %, 98,66 % respectivamente.

Palabras clave: Gemelo Digital (DT); Realidad Virtual (VR); Seguridad de los Trabajadores; Inteligencia Artificial (IA); Educación.

INTRODUCTION

Despite being a vital component of developing the world's infrastructure, the construction sector is still beset by high accident rates that seriously impair project performance and worker safety.(1) A significant amount of money has been spent throughout history on safety planning and monitoring to reduce the probability that these dangers would occur.(2) However, the industry has a higher accident rate than others.(3) The continuance of this problem calls for novel safety measures beyond present ones. VR, serious games, and other tools have emerged from new technology.(4) AI and DT in the DT-CSTF allow us to build more realistic training scenarios and adjust them depending on real-time construction operations and prior safety data.(5) This data may drive automatic virtual reality training scenarios to keep staff up to date on safety precautions. Continual learning should reduce workplace accidents, making them safer and more efficient.(6) Industry stresses people-centered solutions that include intelligent technology and human cooperation. The DT-CSTF platform offers continuous safety monitoring and improvement, which is a tremendous advance for construction safety training.(7) Subsequently the new DT-CSTF framework for construction site safety training is cutting-edge. Digital twins and AI provide dynamic, realistic, and efficient training.(8) This breakthrough enhances VR-based methodologies and establishes the framework for construction safety improvements, aligning with industry aims.(9) A higher safety culture and fewer construction accidents are envisaged from this approach.

Flexible manufacturing systems using modern ICT in production automation are transforming manufacturing processes and management.(10) Innovations form the Industry 5.0 production system paradigm. Smart Factories, Cyber-Physical Systems (CPS), IoT, and Internet of Services make up Industry 5.0, a value chain organization technology and idea.(11) The information-driven flow of workpieces machine-by-machine on a workshop floor facilitated by real-time machine-MES communication is the I5.0 production organization.(12) System in which natural and human-made systems (physical space) are closely linked with computer, communication, and control systems is called CPS.(13) CPS may provide industrial machines autonomous control, self-awareness, and self-management by linking the cyber and physical worlds.

Digital transformation of complex real-world systems is usually business process transformation in enterprise architecture with the right foundation.(14) AI and big dataset-handling technologies revolutionize digital transformation approaches, tools, and processes. Multidisciplinary and creative material that promotes society's well-being and sustainability is essential.(15) It requires support framework openness and cooperation among all necessary social community players. A digital twin is a modern modeling technique for sustainable transformation of complex, operational, real-world systems into a collaborative network of stakeholders. Due to its complexity, such an undertaking requires abstracting and concealing all details until context-dependent data is accessible during elicitation and analysis.

Contribution of this paper

- Create an Innovative Safety Education Method: this seek a complete DT-CSTF including VRTE, construction timelines, safety rules, and BIM. This framework will be developed using Unity.
- To improve worker safety and health: AI will enable the DT-CSTF to monitor construction workers' mental, physical, and emotional wellness in real time. There will get more personalized feedback and customized training situations based on data, improving workplace safety and efficiency.

- Compliance with Industry 5.0 standards is mandatory: DT-CSTF might align with sector 5.0, which seeks to make building safer and more productive. It need solutions that prioritize people and promote close collaboration between intelligent systems and humans to accomplish this aim.

Related work

To promote talent focused on practical applications, the objective of this paper is to suggest novel approaches for integrating education and industry. Hierarchical analysis and CNN methods were used to study this integration's advantages for corporations, educational institutions, and career opportunities. Some think big data and ITIM systems may help schools better serve students and instructors. AI talent is assessed using the IFA-HP technique, focusing on critical competencies. Machine learning predictions reduce the computing burden of operating CPS in SAMPLE. Finally, this section discusses open-source Digital Twin system tools and their potential and the necessity to integrate them.

Convolutional Neural Network(CNN)

A series of inventive development strategies for the integration of industry and education for businesses are proposed in this document to cultivate more application-oriented talent that is required by the market. Since long-term and sophisticated instruction is utilized to evaluate industry-education integration, the indicators are challenging. Hierarchical analysis is used to create a reasonable and clear evaluation index framework, and the CNN algorithm is used to calculate the weight value of each index to fully reflect the impact of industry-teaching integration on enterprises. The evaluation system shows the indicating that the mechanism of industry-education integration promotes the transformation of several courses and helps the employment issues. The worldwide training cost of new employees, which considerably cuts firm recruiting and training costs by integrating industry and education. Thus, CNN in this paper can compute the weight value and conclude that the unique industry-teaching integration method benefits all three parties.

ITIM

Big data technology's incorporation into production processes is becoming standard practice; thus, educational institutions must adapt their pedagogical approaches to meet the demands of students whose lives are more reliant on the digital economy. Business-school collaboration evaluation requires consistent criteria and data visualization. The current teaching method lacks real software experience, overemphasizes theoretical notions, and lacks problem-oriented statistical modeling and big data statistics training. Big data technologies should be implemented and developed via industry-education collaboration. This paper analyses higher education talent training models' flaws and recommends industrial education to fill them. An InterTechnology Information Management (ITIM) system for excellent education is developed and implemented in the paper to bridge the industry-education divide. The ITIM system evaluates education quality using a fuzzy algorithm and offers intelligent functional modules including group administration, financial management and process-to-process communication. The talent training model's experimental findings have improved teaching effectiveness, student learning, and theoretical-applied teaching quality by adding dynamic analysis of industrial education.

IFA-HP

The fast growth of AI technology raises job and talent training standards. Industry-education cooperation helps alleviate the talent shortage posed by industrial demand. Thus, the analysis begins with industry-education integration. It gather industry recruiting texts and process the AI post system's needs using the Latent Dirichlet Allocation (LDA) topic model and Word2Vec and K-means. Then contact analysts and alter the metrics for education. Finally create a four-dimensional vocational ability grade assessment index system that includes fundamental AI, database, network, algorithm and design, and research and practice skills. The index weights are calculated using the Intuitionistic Fuzzy Analytic Hierarchy Process(IFA-HP), which eliminates expert score uncertainty. The largest weight is given to algorithm and design competence, a crucial factor for AI professional talent assessment. Assessments of industries emphasize practical second-level indicators including team spirit, innovation ability, and communication ability, while education emphasizes knowledge and skills such as programming, applied mathematics, data structures and algorithms.

SAMPLE

Digital twinning allows real-time optimization of CPS control and operations using data-driven simulations, but computing loads are prohibitive. Sequential Allocation using Machine-learning Predictions as Light-weight Estimates(SAMPLE), a method for sequential allocation utilizing machine-learning predictions as lightweight estimates, addresses this computing barrier by applying machine learning models learned offline in a predictive simulation learning context before a real-time decision. SAMPLE rigorously but flexibly blends machine learning predictions with data from real-time digital twin execution and optimizes the digital twin simulation to achieve computing efficiency for CPS real-time decision-making. Numerical trials show that SAMPLE can make real-time CPS control and operations choices better than machine learning or simulations.

Open-source technologies

Using the idea of Digital Twins, this paper lays out the best open-source tools and communication technologies for modeling manufacturing processes. Many open-source tools and protocols have been created to generate virtual production system models in recent years. The contributors explain how the Digital Twin idea has evolved into a fundamental technology for Industry 5.0 automation and control. The organized examination of relevant open-source software for different stages and duties of constructing the Digital Twin system showed that the available solutions address all elements. Due to its dispersion, specialization, and lack of integration, this software is seldom used for DT. Thus, integration needs demand extra work to develop full-fledged Digital Twin models using open-source technologies.

Several suggestions for enhancing the combination of business and education are offered in this paper. This integration's talent development and employment advantages may be assessed using hierarchical CNN analysis. It suggests employing big data technologies in schools via the ITIM system to boost learning. The IFA-HP method evaluates AI talent using key competences. The SAMPLE technique uses machine learning predictions to improve CPS control. Digital Twin systems' open-source tools and how to integrate them for Industry 5.0 control and automation are considered as well.

METHOD

High accident rates have a negative impact on project results in the construction business, even if there have been significant expenditures in safety measures. No amount of conventional safety planning or training has been able to completely eliminate these dangers. There is hope that new technology, such VR, might raise workers' awareness of the need of safety measures. The problem is that these VR solutions aren't realistic and usually need a lot of resources. This framework strives to combine buildings information modeling (BIM), building schedules, and safety standards into a dynamic, fully immersive educational atmosphere using the Unity game engine.

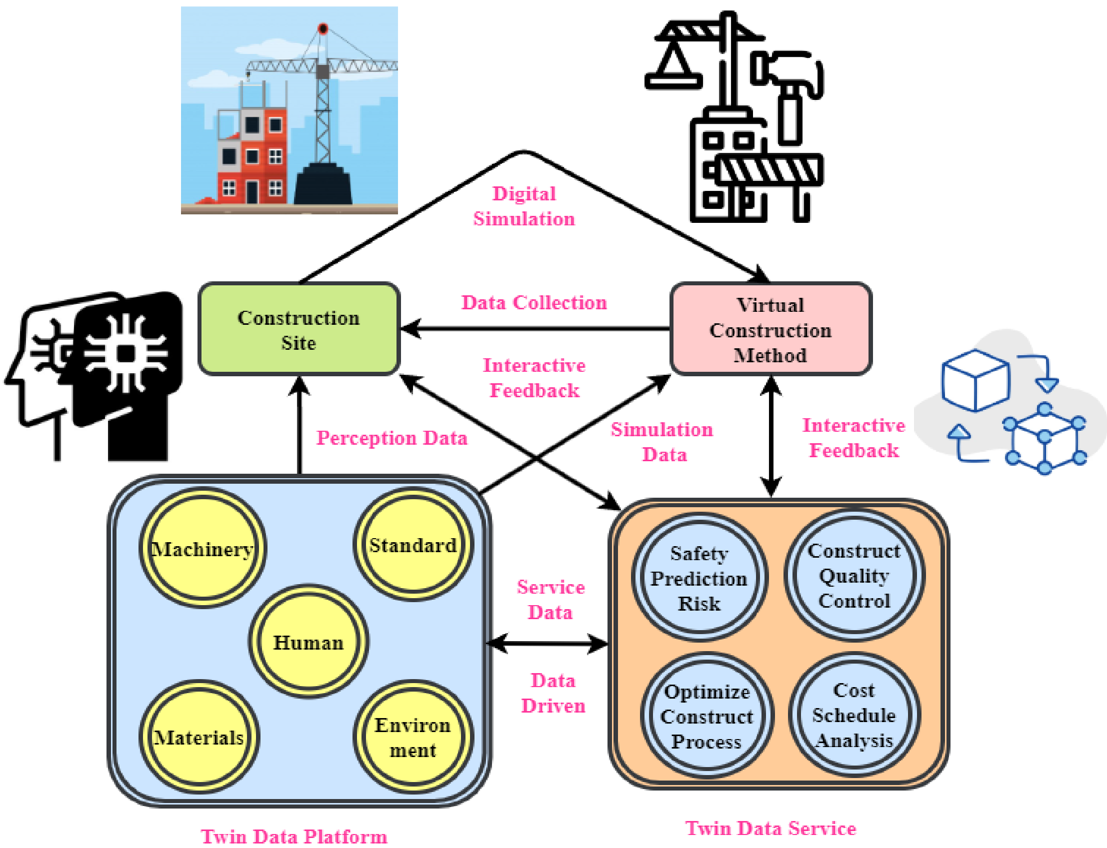

Figure 1. A digital twin frame for use in the building industry

The application of digital twins in a variety of industries, including transportation, electronics, healthcare, smart cities, 3D warehouses, space communication networks, and more. It adds significantly to the growing list of uses for Digital Twin technology. The building sector is likewise making use of the Digital Twin theory. This article presents a Digital Twin architecture for the construction industry is shown in figure 1. The framework creates a virtual building model based on four factors: rules, behaviour, geometry, and physics, all of which are based on the typical physical building site. The data from the real-life building site and the digital model are simultaneously uploaded to the cloud, creating a platform for twin data. The twin data platform sorts the data using the human, machine, material, technique, and environmental factors. The framework may accomplish several services to the algorithms that drive it, including cost schedule analysis, quality control, safety risk prediction, decision trees, BP neural network models, support vector machines, and deep belief networks. This framework has lower construction-related risks and increase the detail level of the process. The equation (1) explains the cost benefit:

$$n_0 \frac{e^2 v_0(u)}{dv^2} + d_0 \frac{ev_0}{eu} + l_0 v_0(u) = g_0(u) \qquad (1)$$

The dynamic reaction of the cost benefit system is denoted by the provided equation 1 n_0, which includes coefficients relating to system sensitivities and damping, denoted as e^2 and d_0, respectively. The system losses and outside inputs are represented by l0and g_0, respectively. Applying this to DT-CSTF, might stand for the current data collected from the site, including the emotional, mental, and physical conditions of the workers, u for different risk factors, and v_0 for the related adaptations to the simulated environment.

$$v_0(u) + 2\forall_0 \times \propto_0 e_0(u) + v_2 m_0(u) = \frac{g\ (h)}{n_0} \qquad (2)$$

The real-world environment's base reaction to user input u might be represented by the expression $2\forall_0 \times \propto_0 e_0(u)$ presumably representing factors for equation 2. The error correction that takes into account real-time data feedback is denoted by $v_0(u)$, while more sophisticated interaction model that incorporates multiple data points is represented by $v_2 m_0(u)$. The efficacy of safety training, as measured by the data $(g\ (h))/n_0$ normalized by the dynamic system response. The equation (3) explains the safety education:

$$t^2 \times v_0(t) + t2x_0 t_0 Z_0(t) + r_0^2 W_0(t) = \frac{l_o\ (p)}{t_0} \qquad (3)$$

The augmented reality's safety education environment's time-dependent reaction is probably depicted by the equation 3 as $t^{\wedge 2} \times v_0(t)$. Here t represents time and $v_0(t)$ represents the state of the system at that particular instant. One possible interpretation of $t2x_0\ t_0 Z_0\ (t)$ is a scaling factor that is associated with particular training parameters r_0^2 and t_0. The effect of these parameters on the learning setting over time is represented by $(l_o(p))/t_0$.

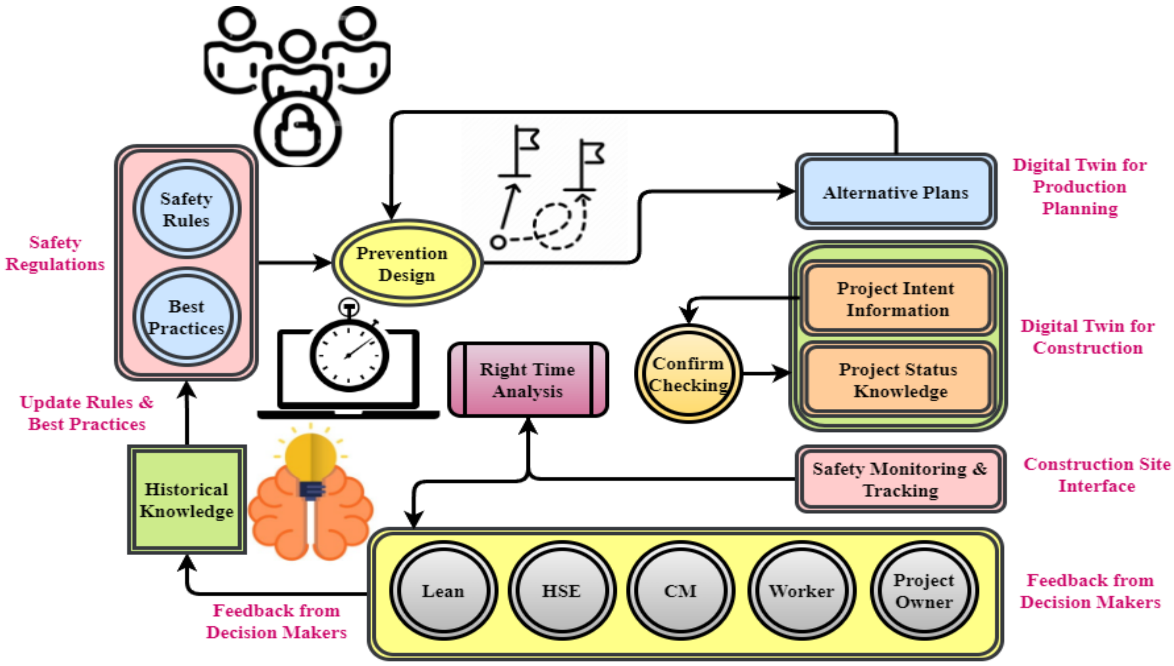

Figure 2. Virtual replica with the purpose of enhancing construction safety Interplay

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Using the most recent data from the DTCS, the blue-represented dynamic virtual reality module updates VR games and conducts periodic worker training. The smart VR setting may provide scenario-specific results for each occurrence by inputting the type of accident and the location into the model. The location and nature of the danger will determine this action. When a game is played, this scenario will automatically generate colliders and data collecting capabilities. The digital twin and the workforce both gain from this. In this way, both the worker and the digital twin get training that may be applied in conjunction with other preventative measures. This information to use when evaluating a plan's Safety Key Performance Indicators (SKPI). Figure 2 shows the digital twin's concept diagram for building security and component interaction. The virtual reality training module that is always being updated is shown in blue. Accidents are happening at a high rate in the construction business, which is having a major impact on how well projects are done. VR simulations provide a more engaging and participatory learning environment for players when compared to traditional safety training techniques. Unfortunately, most current virtual reality games' training settings don't provide the realistic surroundings or complicated activities needed for real building.

$$\propto_{0,1,2} = -\partial_1 z_2 \pm f^{-rst} + \sqrt{1 - C_r} = -\omega_v + t_{u-1} \qquad (4)$$

The equation 4 is denoted by $\propto_0$, where Changes in safety circumstances or worker behavior on the building site may be associated with the variables $\partial_1 z_2$. The system is subject to external influences and probabilistic components through $f^{(-rst)} + \sqrt{(1-C_r)}$, where it represents a factor that may decay exponentially due to risk ω_v or learning decay represents adjustments depending on real-time feedback $t_{(u-1)}$.

$$n\,(u_t) \times \frac{\tau^2 v\,(u, u_t)}{\delta r^2} + d_2(v_r) \times \frac{\gamma_2(k_1, k_2)}{\varepsilon u} + g(u, u_h) \qquad (5)$$

In the equation 5, $(\tau^2 v(u,u_t))/(\delta r^2)$ represents the time-dependent reaction of the online training system scaled by safety-related parameters n (u_t). The equation $d_2(v_r)$ reflects the changing response of the system depending on user input $(\gamma_2(k_1,k_2))/\varepsilon u$. The general performance measure or result depending on user input and previous data is probably represented by $g(u,u_h)$.

$$l \times (u_v) = k_1, \int_0^{V_g} l^2 \times [u_t] + v_q < \infty, \qquad 0 < U_t < \infty \qquad (6)$$

The exponential connection among the training parameter l and the user variable u_v, which leads to the constant k_1, is represented by the equation 6. The total effect of the squared learning parameter l^2 and user input u_t on the whole training environment is shown by the integral v_q across the volume U_t.

Using the built-in Unity Game Engine, the AI Module flows into a virtual reality training environment that incorporates construction schedules and BIM. To make sure the training situations are reflective of real-world restrictions and requirements, this environment includes Safety Requirements. Users can then participate in virtual building tasks through the creation of automatic VR game learning scenarios. Scenario Creation, Gathering Data on Risks and Reactions from Users, and a Customized Feedback Mechanism for Improvements and Insights are All Made Easier with These Scenarios. Lastly, the system is designed to facilitate Periodic Building Safety Monitoring, which includes collecting data continuously and making training modifications on the fly. This guarantees that safety training is always up-to-date and relevant, which improves site safety overall and addresses new threats as it arise. The equation (7) explains the effectiveness of Virtual Reality-Based Security Training analysis:

$$l\,(u_t) + n\,(u_t) = n_0\left(1 + \nabla_p(s_u)\right) + l_0\left(1 + \nabla_q(u_f)\right) \qquad (7)$$

The impact of user input u_t on parameters for training l and n (u_t) are shown by the equations 7. The initial states of the training environment are represented by the variables n_0 $(1+ \nabla_p(s_u))$ and l_0 $(1+ \nabla q(u_f))$, which are modified by gradients respectively.

Figure 3 shows the overall structure of a construction security education program that aims to improve safety procedures by utilizing cutting-edge technology. Foundational data, such as Project Intention and Status Data, Safety Criteria Data, and Historical Data, are first collected by the system. This data provides crucial context for the succeeding operations. The AI Module is the brains of the operation; it generates feedback, assesses

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risks, and keeps tabs on users' mental, emotional, and physical health in real time. Ongoing supervision and preventative risk management are guaranteed by this module.

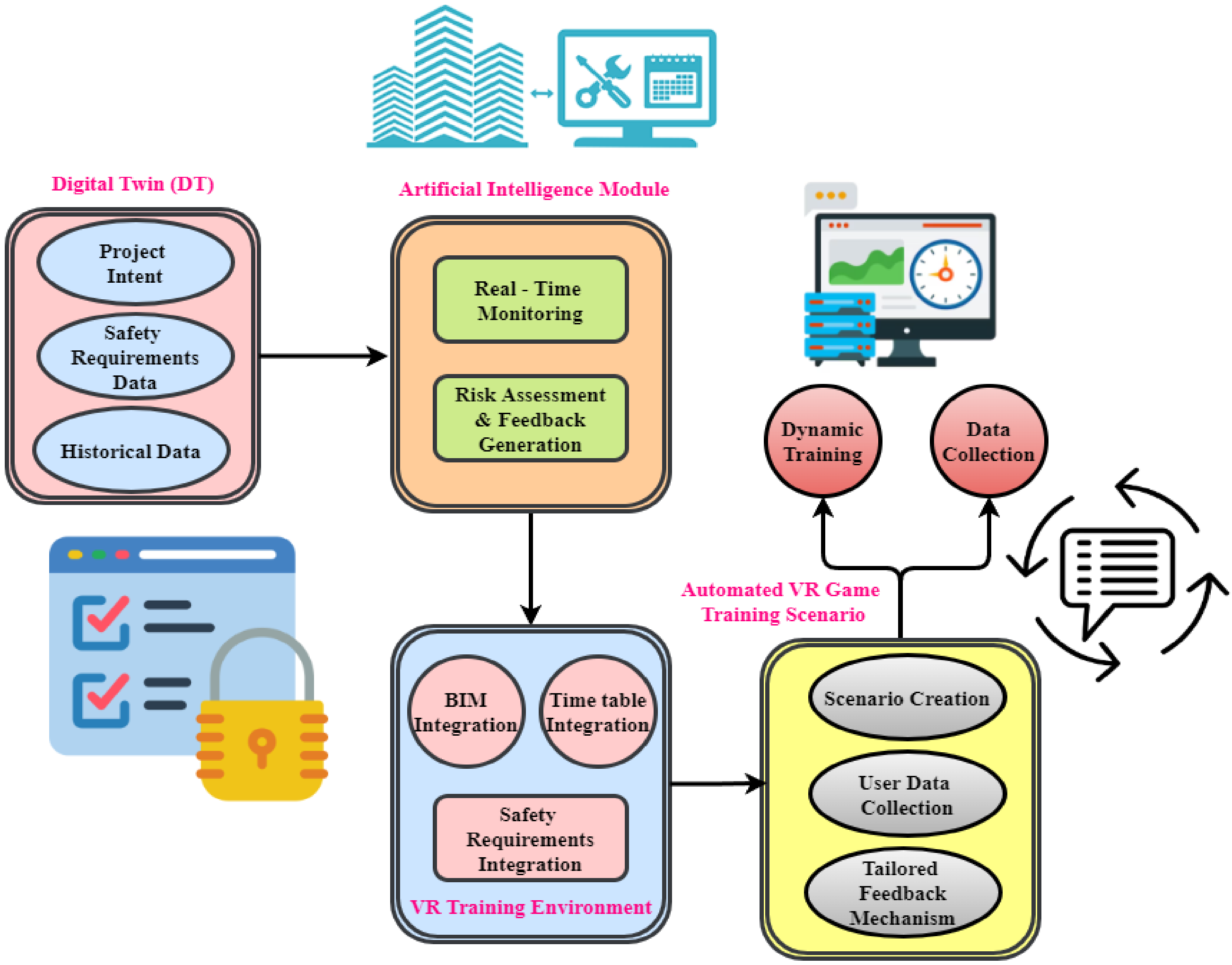

Figure 3. Enhanced System for Construction Safety Education

$$\nabla_l(u_t) = f^{-\beta_l+v_t}\left(\frac{1+\ v_j \sin(\alpha_t \times v_t)}{1+s_t}\right) - 1 \qquad (8)$$

To illustrate the impact of changes in user input on the training environment, the equation 8 $\nabla_l(u_t)$ shows the change in gradient of customer input. It is probable that the function $f^{(-\beta l+vt)}$ modifies the effect of user input depending on parameters like the importance $1+s_t$ of the training component and user participation ($1+v_j \sin(\alpha_t \times v_t)$.

The proposed method for managing the safety risks associated with raising prefabricated buildings is depicted in figure 4. To link the hoisting virtual model to the hoisting construction site, the framework employs the Internet of Things (IoT). An association between virtual and actual mapping is completed by constructing a two-way data synchronization channel connecting the physical and virtual spaces, based on data transfer protocols with low latency, high stability, and speed. A prefabricated house hoisting risk couplings study is carried out using the complex network based on the data mining results obtained from the Apriori algorithm, which is utilized to identify the principles of association among different threat systems or components. The BIM model is used to finish the virtual space modeling process.

The digital twin architecture, which offers features like decision-making and early warning, relies on the BIM model to visualize the data service platform. In that manner, both the digital model and the physical location may communicate and share information in real time. Prefabricated building hoisting safety risk coupling model construction is the main topic here. One way to study the coupling impact of safety risk variables is to look at the model's multi-source data and see how the virtual and actual interact with each other. Lifting danger is defined along five dimensions in the data provided by the connections model of the assembly.

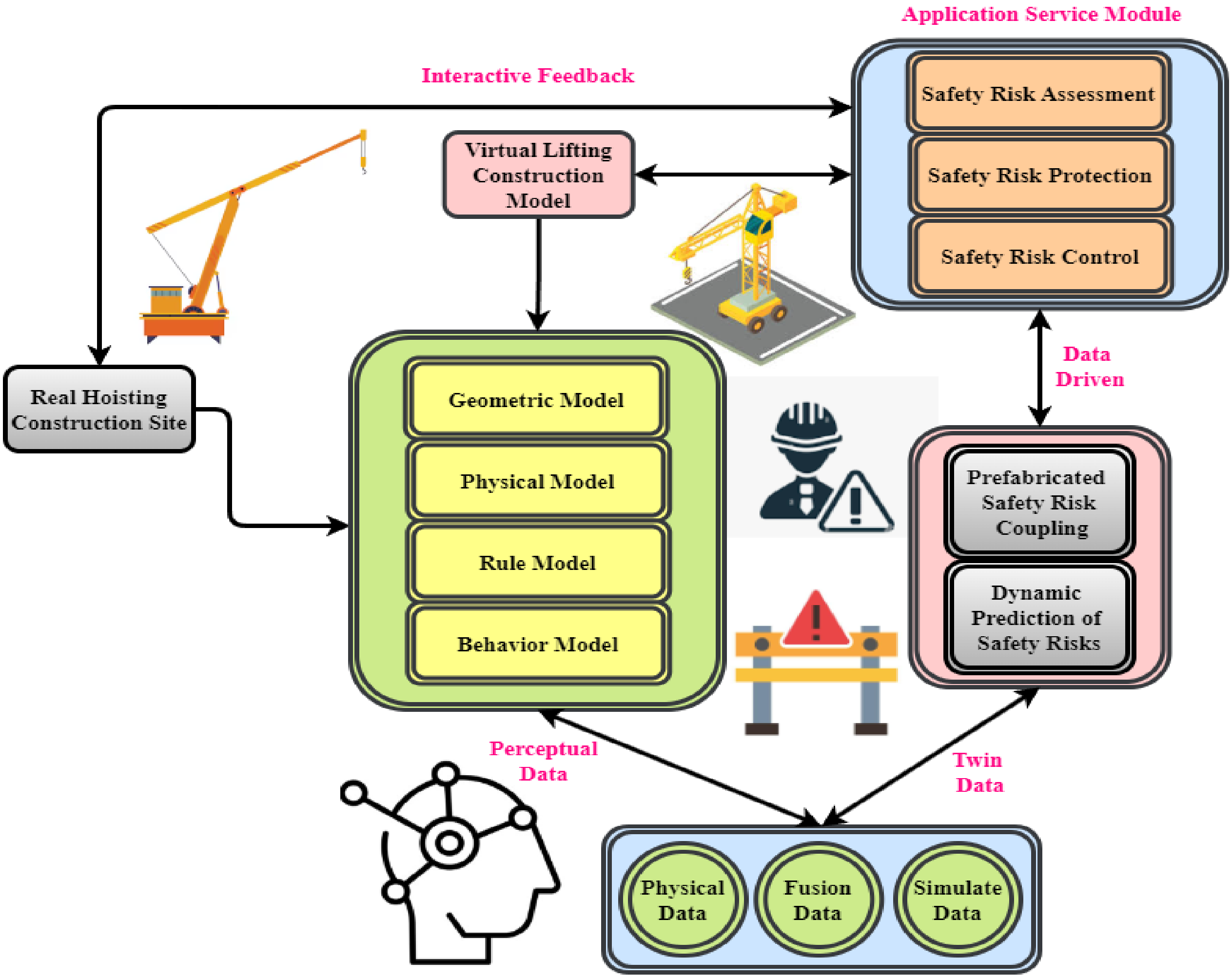

Figure 4. Standardization of prefabrication building hoisting safety risk management

$$\forall_n z_v = \propto_p (1+sp) \times \beta_n (s_v - \delta/\varphi_p) \quad (9)$$

A collective parameter impacting the simulated learning surroundings, the equation 9, $\forall_n z_v$ probably indicates the total influence of various factors on the training system. It is probable that $\propto_p(1+sp)$ represents a scaling factor that is modified by safety-related factors. Integrating a deviation element β_n modified by protection thresholds (δ/φ_p).

$$z_0 \times \frac{f^2 \times v(u)}{eu_2} + d_0 \frac{ef(b)}{dw} + l_0(1 + \forall_l (u_r)) = g(u) \quad (10)$$

It is probable that the equation 10, z0 is a baseline parameter that impacts virtual instruction circumstances, showing its early impact on the learning system. The squared modulator function (f) is likely to reflect the significance of user involvement (u) controlled by further variables ((ef(b))/dw) as suggested by the phrase $(f^2 \times v(u))/(eu_2)$. An external condition (b) and potentially additional variables are modified by the sensitivity of the training system (l_0) and the effect of these conditions on the setting for training $(\forall_{(l)}(u_r))$ in the expression g(u).

$$e(B,C) = \sqrt{(B-C)^I(B-C)} = \|B-C\|_2 \quad (11)$$

Equation 11 denotes the analysis of performance e(B,C) shows the size of the difference between the states or attributes of two vectors (B-C) by expressing them as the Euclidean distance that exists between them. Within the framework of the DT-CSTF, this might stand for the discrepancy between the building's safety training environment's ideal or intended condition (B) and its actual state (C).

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$$e_1(u_t) = e\left(\beta e_0 . \alpha_\exists, (u_f)\right) + e_1(u_k) = \frac{e_1(u_f)}{q_2} \qquad (12)$$

The analysis of monitor employees emotional is denoted in the equation 12 $e_1(u_t)$. The external stimuli $\beta e_0 . \alpha_\exists, (u_f)$, and user feedback e_1 (u_k)impact the equations that reflect their emotional state at time $(e_1(u_f))/q_2$.

The agents involved face regular, unexpected obstacles on a building site, which adds to the site's intrinsic complexity. This is a major contributor to the high accident rates that affect even seasoned employees. By simulating real-world conditions as much as possible during training, accidents can be drastically decreased. The workers are given training situations in the dynamic virtual reality games that are built from the digital twin of their actual building site. As tasks are completed, the training situations are revised accordingly. Workers are able to execute their jobs, make errors, and gain experience without worrying about harming themselves. In Figure 5, see the overall plan for creating and implementing the VR training games that are always evolving. Historical data, safety rules, and an object library are just a few of the digital copies of datasets used to build the initial set of training situations. The data coming in from the digital twin is then used to update the training settings on a regular basis. Creating realistic safety training situations calls for precise geometric data, well marked danger zones, and interactive items. From the project Intent Data, the first geometry for the training environment is generated using the as-designed parametric models alongside instructional activities according to the as-planned method.

$$\frac{e_1(u_f)}{q_2} = \sqrt{1 - d_p^3} = \sqrt{1 + \nabla_l(u_r) - s_2^p} \qquad (13)$$

The analysis of safety requirements is determined in the equation 13 for the feedback $(e_1(u_f))/q_2$, modified by a factor d_p^3, is represented. In addition, parameters like risk deviation (∇_l), user reactions (u_r), and safety limits (s_2^p) impact safety-related factors. The equation (14) is explains the employee behaviour:

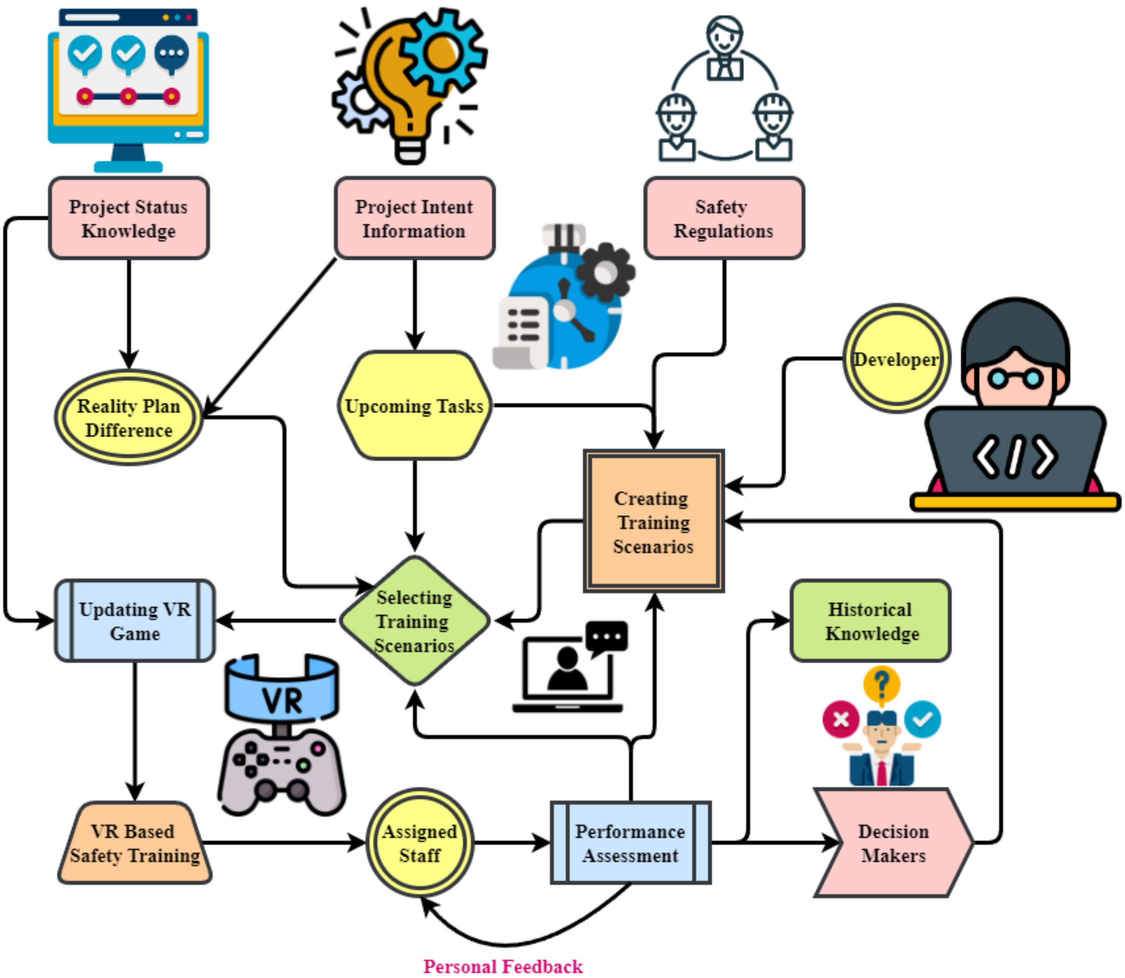

Figure 5. A virtual reality (VR) training framework for adaptive building security

$$\delta_v(y_z) = -e_2(f_e) \times \left(2\sqrt{1 - D_{f1}^{f2}}\right) + \frac{2w}{f} \qquad (14)$$

The safety parameter $\delta_v(y_z)$ is denoted by elements on employee behavior $e_2(f_e)$ and the surrounding environment D_{f1}^{f2}, and it is connected to a specific component of safety planning. The adjustment factor is dependent on the efficacy of protection measures (f_e) and the variations between two safety variables (D_{f1}^{f2}). Furthermore, 2w/fis affected by both external circumstances and the efficacy of security preparation which adds to the thorough examination of safety planning in the framework. The equation (15) explains monitoring the Well-being and Security of Employees:

$$\forall_D \times r_e \approx -f1 \times k_e(2 - e_1[w2] + [e1]) \qquad (15)$$

Construction safety monitoring is denoted by factors including security norms ($\forall_D$) and surroundings r_e, which are represented by the equation 15. An adjustment factor that takes into account the effectiveness of safety measures (f1), the impact of user engagement k_e, the square of a safety-related parameter w2, and the emotional state of employees (e1) is represented.

A new framework called DT-CSTF is being considered to improve construction security instruction by utilizing the power of AI and DT. Data from twins, including project goals, progress, safety standards, and past data, are used to automatically create virtual reality training situations. Regular revisions and immersive simulations are part of this dynamic approach's plan to boost building security surveillance and the efficacy of safety training generally.

RESULT AND DISCUSSION

Analysis suggests that tailored feedback may drastically reduce accident rates. Consequently, a more effective safety education system may be created by combining tailored feedback with virtual reality safety training. This system has the ability to raise workplace safety and minimize occurrences.

Dataset Description

An extensive overview of a wide and comprehensive dataset, precisely produced by the sophisticated language model is given in this paper.[21] The goal of this comprehensive dataset is to provide a starting point for investigations into many different areas, such as renewable energy, AI, worldwide health trends, and many more. Subjects Included in the Dataset: A Wide Range of Topics, From Renewable Energy to AI to Global Health to Digital Media to Space Exploration to Genetic Research to Urbanization and Beyond. Each dataset item has a model-generated, in-depth answer that covers several facets of the provided subject.

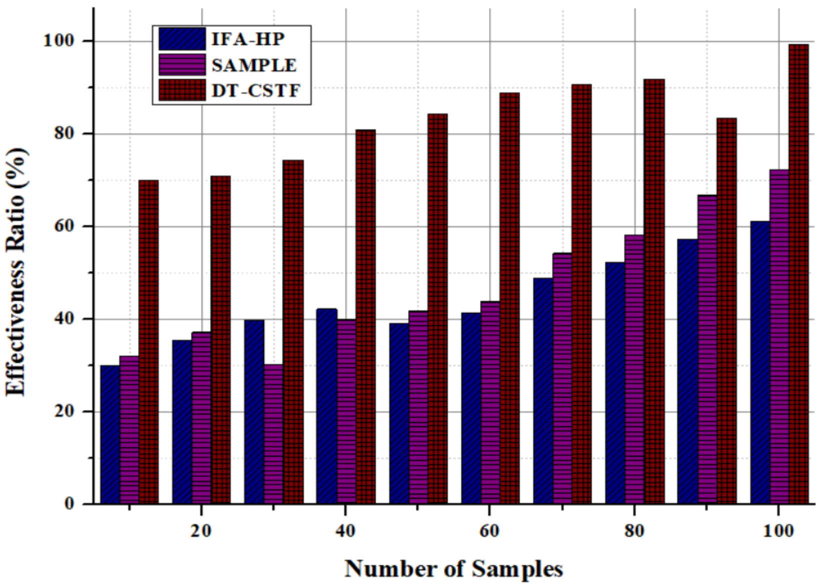

Figure 6. Effectiveness of Virtual Reality-Based Security Training analysis

Workers' involvement and memorization of safety requirements are enhanced in VR-based safety training when they get tailored feedback. Quick and relevant feedback is given to workers, which aids in reinforcing learning and discourages bad behaviours is described in figure 6 and equation (7). This is achieved by tailoring training scenarios to meet the needs of each individual and promoting the use of immediate responses. Workers are more inclined to fully embrace safety practices when they are given the opportunity to understand the unique safety requirements of their jobs via this personalized approach. Several investigations have shown that by tailoring feedback to each worker's unique set of circumstances, the chance of accidents may be significantly reduced. In addition, when employees get tailored feedback, they are prone to stay engaged and motivated throughout training sessions since they will feel that their specific growth is being acknowledged and guided. Incorporating personalized feedback into VR safety training might lead to a more efficient and effective safety education system, which in turn could bring about a rise in workplace safety and a fall in incidents. The analysis of effectiveness is obtained by the ratio of 96,90 % in the proposed method.

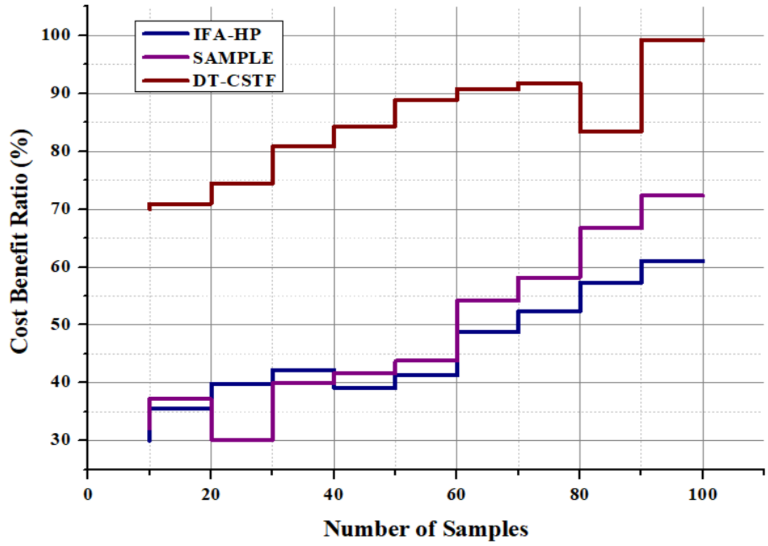

Figure 7. Analysis of cost-benefit

The DT-CSTF, does need a number of upfront costs to be covered with the help of equation (1). Expensesinclude things such as staff training, system integration and technology acquisition. The benefits is described in figure 7 in the long run, however will more than cover the costs of the upfront cost. Reducing the number of accidents means less money spent on healthcare and compensation and making workplaces safer means more output from employees since they aren't out of commission as often. Reduced need for and associated costs with frequent retraining sessions is one benefit of DT-individualized CSTF's monitoring and training capabilities, which contribute to the continuous improvement of safety standards. Although there is a significant financial investment required, the overall improvements in safety and operational efficiency achieved by DT-CSTF provide a compelling return on investment, making it a cost-effective option for the construction industry. In this proposed method the cost benefit analysis ratio is increased by 98,33 %.

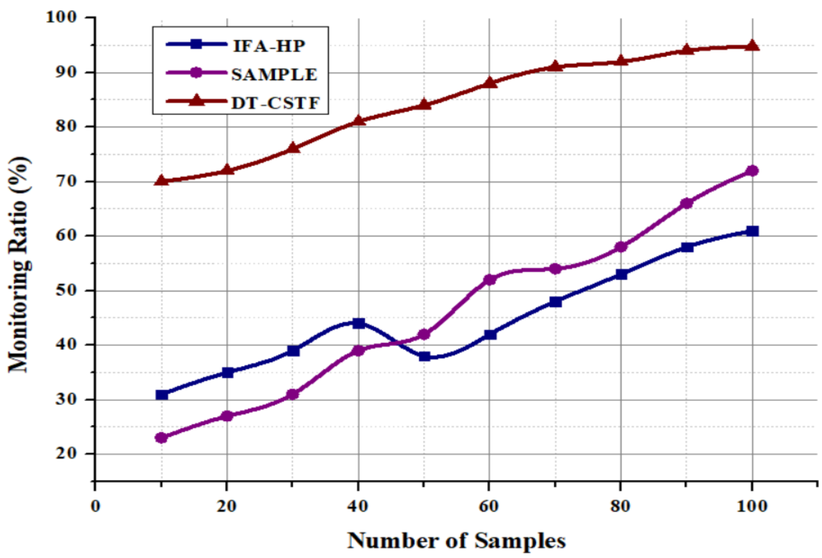

Figure 8. Analysis of monitoring on the Well-being and Security of Employees

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Improving safety outcomes for construction workers may be achieved in figure 8 and equation (15) via the use of DT and AI technology to monitor their emotional, mental, and physical health in real-time. Because it continuously measures pulse, blood pressure and levels of stress and fatigue, the device may identify potential health issues before they lead to accidents. Workers will remain in the best possible condition attributable to this proactive methods, which enables the implementation of prompt interventions through enforced breaks or job relocation. In addition to allowing for the continual updating of training programs, real-time data provides substantial insights into the efficacy of safety legislation and worker behaviors. This, in turn, creates a healthier and more productive work environment. In general, DT-CSTF's integration of real-time monitoring contributes to a more health-conscious work environment, which in turn decreases the occurrence of incidents and enhances the overall welfare of employees. Compared to the existing method the analysis of monitoring on the well- being and security of employees in the proposed method is obtained by 99,25 %.

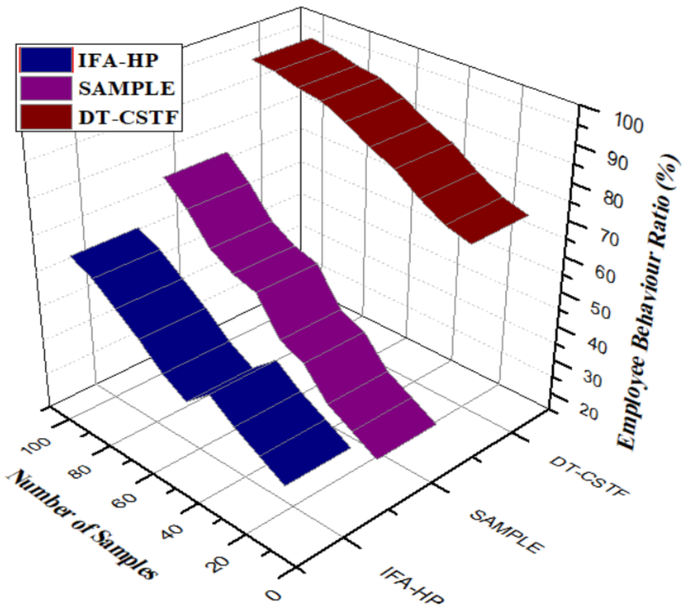

Figure 9. Analysis of Managing Employee behaviour

Working within the framework of the DT-CSTF, the integration of AI and DT technologies has a substantial impact on the well-being of employee is shown in figure 9 and equation (14). Virtual training environments allow workers to obtain experience and practice in a controlled setting by mimicking real-world scenarios. This gives employees the chance to learn how to handle potentially harmful circumstances which is shown in figure. According to this concrete strategy, they are more prepared and confident in their abilities to handle real challenges on-site. The framework's real-time monitoring features also allow for continuous evaluations of employees' mental and physical well-being, guaranteeing that they are healthy enough to do their jobs. Personalized feedback and flexible training programs provide extra support for individual needs, promoting a comprehensive safety strategy. Taking a holistic view of the problem helps to reduce accident rates and fosters a positive work environment where employees' safety and well-being are valued. Therefore results in higher levels of contentment with one's work and total output. The analysis of managing employee behaviour ratio is 95,91 % in the proposed method.

The incorporation of VR-based safety training represents a significant advancement in the field of construction safety education is explain in the figure 10 and equation 3. The development of comprehensive and realistic recreations of construction sites has allowed employees to engage in practical training without exposing themselves to the risks associated with working in a real-world setting. Standard training techniques have a hard time recreating real-world emergencies, but this method allows for the practice of safety procedures in a range of conditions. Worker retention is enhanced by using VR technology since it increases the possibility that workers will remember and apply what they have seen personally. Not only does this approach improve workers' safety capacities, it additionally also fosters a culture of continuous learning and growth inside the company. Consequently, a powerful technique that can be used to increase construction site safety and decrease accident rates is the integration of VR into safety training programs. The analysis of safety education is obtained by the ratio of 98,66 % in the proposed method.

Safety training in the construction industry may be greatly improved with the use of virtual reality by creating realistic training scenarios and providing personalized feedback. There is a decrease in accident rates because the tailored approach improves worker involvement and retention of safety requirements. Reduced healthcare expenses, fewer need for retraining and increased production are just a few of the long-term benefits that outweigh the initial expenditures. Utilizing DT and AI technology to monitor workers' health in real-time allows for preventive steps, which further enhance safety outcomes. A safer and more productive workplace is the inevitable consequence of this all-encompassing plan's execution since employees will be better equipped, healthier and more motivated. To enhance safety and reduce incident frequency, VR may be included into training programs.

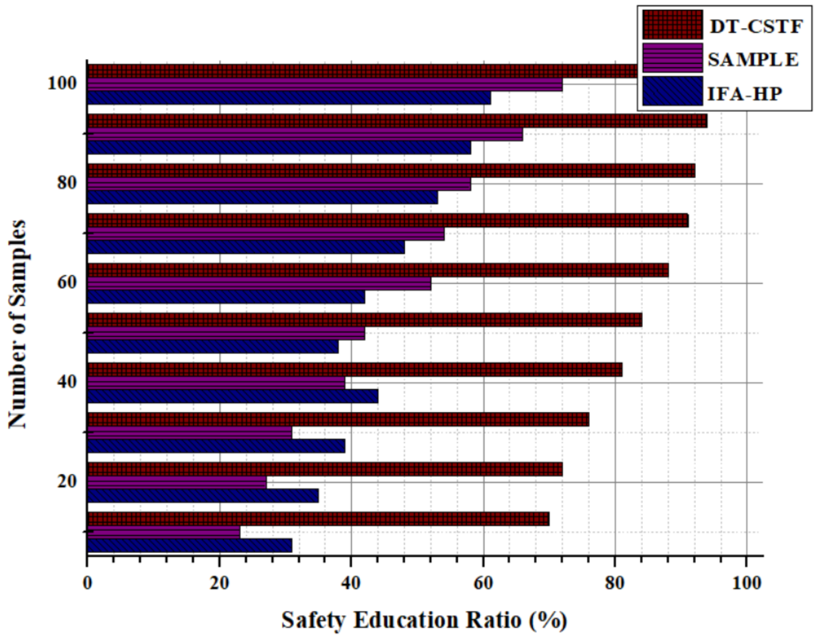

Figure 10. Analysis of Safety Education

CONCLUSIONS

The construction industry continues to confront safety concerns that necessitate innovative approaches that surpass conventional methods. Using modern technology to provide a realistic and ever-changing training environment, the proposed DT-CSTF with Artificial Intelligence offers a groundbreaking approach. By integrating Building Information Modeling (BIM), construction schedules and safety standards into a VRTE using the Unity game engine, DT-CSTF may increase the immersion and efficiency of safety training. By combining real-time worker health monitoring with adaptive training situations, it can guarantee that each worker receives customized and pertinent safety teaching. This framework aligns with the human-centric approach of sector and aims to reduce accidents in the construction sector while strengthening safety culture. It does this by addressing the limitations of existing VR-based techniques.

Future work will primarily concentrate on refining the DT-CSTF to increase both its accuracy and the user experience. Incorporating more sophisticated AI algorithms to enhance real-time monitoring of workers' mental and physical states will be prioritized. Adding additional diversity to the virtual reality situations with respect to building operations and related dangers is another important step toward ensuring comprehensive training coverage. Also will conduct field trials to see how well the framework works in actual settings. The results of these tests will be valuable for making incremental changes. In an attempt to enhance the system's predictive capabilities, there will be an effort to establish partnerships with construction businesses to gather a considerable quantity of data. The eventual goal is to have the DT-CSTF become a standard training tool for the construction industry, which will lead to major improvements in worker safety and protection.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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