Application of Virtual Reality Simulation as a Tool for Safety-Related Training in the Steel Industry

Hazards are ever-present in the steel plant environment, and a heightened awareness and emphasis on safety is a necessary priority for our industry. This monthly column, coordinated by members of the AIST Safety & Health Technology Committee, focuses on procedures and practices to promote a safe working environment for everyone.

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Comments are welcome. If you have questions about this topic or other safety issues, please contact safetyfirst@aist.org. Please include your full name, company name, mailing address and email in all correspondence.

Due to the nature of the job, workers in the steel industry are inherently threatened by a range of hazards inside the steel plant, which have the potential to cause serious injuries or even fatalities. These hazards include heat, toxic gases and a working environment with close proximity to moving equipment such as cranes, trucks and forklifts. Equipment-related safety hazards include collisions, entrapment between moving equipment parts, as well as exposure to high-energy sources such as heat, electricity and pressurized fluids. During the last decade, steel producers have significantly improved their safety performance, which is reflected by the significant reduction in the lost-time injury frequency rate (LTIFR), which measures the number of lost-time injuries per million man-hours. According to the World Steel Association, the global steel industry LTIFR went from 4.55 in 2006 to 0.83 in 2019, equivalent to an 82% decrease (Fig. 1). Even though this trend shows a significant improvement of the safety level in the steel industry, there is still much progress to be made in order to achieve the ultimate desired goal of zero accidents.

Ternium is 100% committed to achieve this very goal in all its facilities and industrial complexes and therefore is continuously improving working conditions, operational practices and safety-related training.

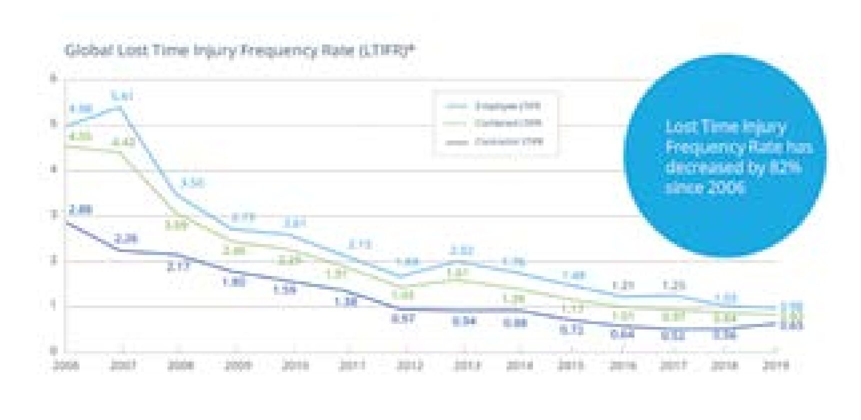
Carter and Smith[2] and Namian et al.[3] pointed out, based on data of the construction industry, that hazard recognition and the accurate perception of safety risk are key components of any safety program. Hazard recognition is by definition the clear and distinct recognition of anything that by condition or behavior has the potential to cause harm to people, damage to property or environment, or loss of process. Therefore, when hazards remain unrecognized or the associated safety risk is underestimated, the likelihood of catastrophic and unexpected injuries increases dramatically. The provided safety training should give employees the ability to become familiar with potential hazards in their daily working environment and recognize and manage them in order to reduce injuries, incidents and so-called "near misses."

According to Namian et al.,[3] traditional classroom training utilizing textbook content or even videos (low-engagement training) cannot provide the learning experience in order to guarantee the required ability of hazard recognition. Accordingly, new means of training have to be developed and introduced in order to provide the necessary high-engagement training. On the other hand, as pointed out by Susi et al.,[4] the reproduction of hazardous situations and accidental outcomes in a "real-world" environment is challenging, due to the involved risks, expenses and time.

As a consequence, Jeelani et al.[5] incorporated in their training programs elements known to improve stimuli or threat detection like visual cues to aid systematic hazard search, personalized hazard recognition performance feedback, personalized eye tracking, visual attention feedback and metacognitive prompts that trigger the adoption of remedial measures. Schofield et al.[6] concluded that "the capacity to remember safety information from a three-dimensional computer world is far greater than the ability to translate information from a printed page," and therefore virtual reality

(VR) simulation offers an opportunity to improve considerably a safety related training. Recent studies illustrate that employing eye tracking and VR technologies in safety training programs can outstandingly enhance workers' hazard recognition skills (Jeelani et al.,[7] Zhao and Lucas[8]). Many of the training systems using VR are designed as "serious games" (Lee et al.,[9] Westera et al.,[10] Michael and Chen,[11] Van Rosmalen et al.[12] and Le et al.[13]). In that context, Burke et al.[14] pointed out that a serious game's learning engagement is much more important for the educational effect than the ultimate emphasis on realism and visual representation.

Figure 1



Lost-time injury frequency rate (LTIFR) from 2006 to 2019.[1]

The present work describes the development and implementation of a VR hazard recognition training system incorporating the continuous casting area of Ternium Brasil's steel plant with the following main purposes:

- Making a step forward to the ultimate goal of zero incidents.
- Increasing considerably the quality of the safety training by using VR technology.
- Increasing the employees' ability of hazard recognition in the steel plant, especially for those that visit the operational area infrequently.
- Familiarizing newly contracted or non-permanent workers with the hazards and risks of their new working environment even before entering the operational area.

This project was a cooperation of Ternium Brasil (operation, IT, safety), Ternium University (integration of the training content), TESSA (systems and framework) and Firjan SENAI RJ (modeling and system development).

Hazard Assessment

The development of a VR hazard recognition training system for Ternium Brasil's steel plant was planned in two phases. The first phase, which is described in the present work, includes the external and internal area of the continuous casting area. The second phase, including the basic oxygen furnace (BOF) and secondary refinement area, was executed as an extension of the first project phase in the same way as described in this work.

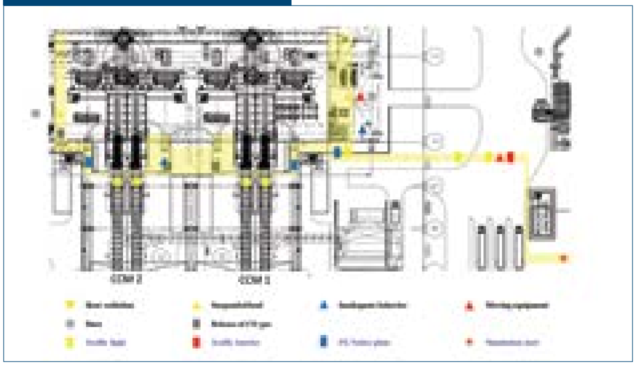
The very basis for the development and implementation of the VR hazard recognition training system was

Figure 2

	Rule title	Description
1	Entrapment	Avoid exposing yourself to risk of entrapment.
2	Energy isolation	Block effectively and ensure zero energy before operating the equipment.
3	Working at height	Wear a safety belt, lifeline and signalization when working at height.
4	Suspended load	Keep a safe distance from suspended loads.
5	Gas	Get the safety data sheets and emergency measures know before working with gases and dangerous substances.
6	Confined space	Only enter confined spaces with proper authorization
7	Mobile equipment	Operate only mobile equipment for which you are qualified for. When interacting with moving equipment, keep a safe distance.
8	Electrical installations	Work on electrical installations only if you have been trained and use specific Personal Protective Equipment (PPE).
9	Work evolving heat	Perform work evolving heat only with authorization and appropriate training.
10	Shortcuts	Always follow the rules and procedures, never take shortcuts. Respect the signs and use PPE. If the risks are not properly controlled, refuse the task.

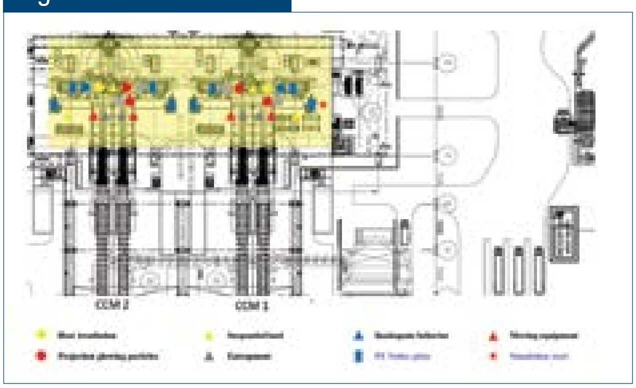
Ternium's 10 life-saving rules.

Figure 3



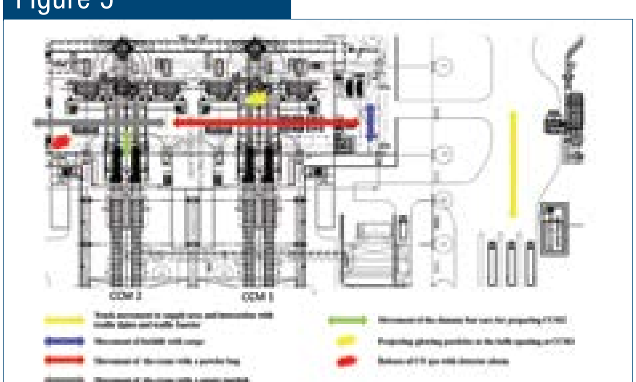
Layout of the simulation of the "secure walkway area" including hazard potentials and additional hazard — or simulation related information.

Figure 4



Layout of the simulation of the "operational area" including hazard potential and additional hazard — or simulation-related information.

Figure 5



Additional hazard — or simulation-related animations.

the hazard and risk assessment based on Ternium's 10 life-saving rules, which are listed in Fig 2. These rules focus on the daily operational and maintenance activities which, through data analysis, have been shown to most likely result in accidents and fatalities and help generally to manage risks associated with the daily work. Based on these life-saving rules, the most relevant risks and hazard potentials were assessed in the area throughout various inspections, interviews and audits and are listed in Table 1.

It should be noted that only risks which are generally relevant when walking to or through the continuous casting area using the secure walkway or inside the operational continuous casting area were taken into account. Risks related to typical maintenance tasks, like energy isolation or working at height, were not considered in this project since these tasks are very specific for the maintenance personnel and are addressed in special trainings.

The continuous casting area with its two continuous casting machines was divided into two distinctive simulation areas:

- The "secure walkway area" for accessing and passing through the operational area, where only standard personal protective equipment (PPE) like a helmet, boots, protective glasses, gloves, ear protection and CO_2 sensor is required. The secure walkway is marked with a distinctive green color and yellow borders and provides a secure translation to and inside the continuous casting area. Even using this secure walkway, where a safe distance to the operation is always maintained, cautions regarding hazards like moving vehicles, suspended loads, etc., still have to be taken.
- The "operation area," including the casting machine, where the use of additional heat-resistant PPE such as a jacket, trousers, gloves and hood is mandatory. This area includes the area near the continuous casting machines, where additionally to the risks of the secure walkway, specific risks regarding to the continuous casting operation like heat irradiation, projection of glowing particles, etc., are present.

The physical extents of these two areas are shown in Figs. 3 and 4 together with hazard potentials and additional hazard-related information like traffic lights, barriers and the starting position of each simulation.

In order to enhance the educational effect of the simulations, various hazard- and risk-related animations were included in the simulation like moving trucks, forklifts, cranes and dummy bar cars (see Fig. 5). Additional ambient effects like shimmering air due to heat, dust and steam clouds were added as well.

Table 1

Main Risks at the Continuous Casting Area

Risk Type	Source/Position	Life-saving rules
Heat irradiation/ projection of glowing particles	Free exposed liquid steel surface of the tundish and mold generating heat irradiation and projection of incandescent particles	9 and 10
Heat irradiation	Heat radiation generated from the strand leaving the caster	9
Heat irradiation/gas leakage	Heat irradiation and possible gas leakage generated in the area of SEN heaters	5 and 9
Noise	Noise generated by machines, equipment and production processes in the entire area	10
Dust	Dust generated due to the handling and use of mold flux powder and tundish cover powder	10
	Dust generated from other areas such as the supply area, ladle and tundish preparation, and refining area	10
Suspended load	Transport and handling of ladles, tundishes, segments, molds, powder bags, refractory boxes, etc., using hoists and overhead cranes	4
Moving equipment	Trucks cross walkways before unloading raw materials such as lime at the bays	7
	Forklift movement in the material receiving area	7
Moving equipment/ entrapment	In order to insert the dummy bar into the casting machine, the dummy bar car is moved from its parking position to the mold position	1
Inadequate behavior	Inadequate or lack of personal protective equipment (PPE)	10
	Use of cell phone outside the reserved area	10
Carbon monoxide	Release of CO gas in the secondary refinement area	5

System Development and Gameplay

The VR simulation was implemented as a serious game based on available 3D CAD data and a considerable amount of 360° images taken during site visits using a state-of-the-art real-time 3D development platform. The used VR system includes the VR headset, two handheld controllers and high-resolution headphones. The movement through the simulation area is controlled with the thumb of the right controller, which triggers a pointer to teleporting spots marked at the floor. The trigger button on the same controller, which is operated with the forefinger, is used to point to and confirm detected hazards. The goal of this serious game is the detection of six different types of potential hazards during 15 minutes of gameplay in a specific area in the steel plant. The detected hazard types, the remaining of six available "lives" and the already elapsed simulation time is shown together with the pointer connected to the left controller (see Fig. 6).

After a potential hazard is highlighted by pointing to an object (vehicle, heat source, smoke, avatar, moving object, etc.) a pop- up window opens offering four possible hazard types related to the object to choose from (see Fig. 7a). After confirming the right choice, the related hazard icon shows up together with the adequate life-saving rule for further explications (see Fig. 7b). Wrong choices result in the subtraction of one of the remaining lives.

Each time the player enters an area with a potential life-threatening risk, like a walkway blocked by a stop signal or the area directly below a suspended load, a pop-up window informs the player about their severe error and consequently one life is subtracted from the player's still available ones. False positive risks are also included in the gameplay in the "safe walkway" simulation. While these risks are physically present (for example, glowing particles coming from the continuous casting mold), the distance between the player at the safe walkway and the risk is too big to represent a relevant risk. A pop-up window informs the player about this false positive risk perception. The information of lost lives and false positive risks are also documented in the final evaluation report.

In both simulation areas, different types of warning signs related to the use of the adequate PPE, cellphone use, etc., were exactly reproduced in the simulation (appearance and position) as shown in Fig. 8.

Additionally, the typical sounds of a steel plant, including the warning sound of the overhead cranes, moving dummy bar cars and even robots on the casting platform, were recorded during site visits and are played during the simulation in order to

Figure 6

Pointer connected to the left controller showing six different types of hazards, remaining lives and elapsed simulation time.

Figure 7

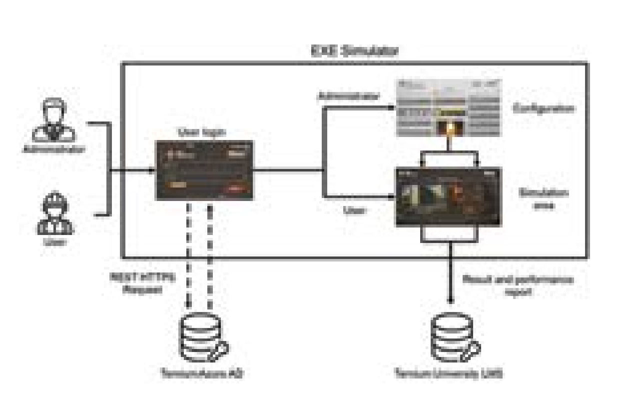
(a) (b)

Hazard detection pop-up window with four possibilities to choose (a) and additional explication of the correctly chosen hazard type (b).

Figure 8

Warning and information signs integrated in the VR simulation.

Figure 9



Basic layout of the simulator.

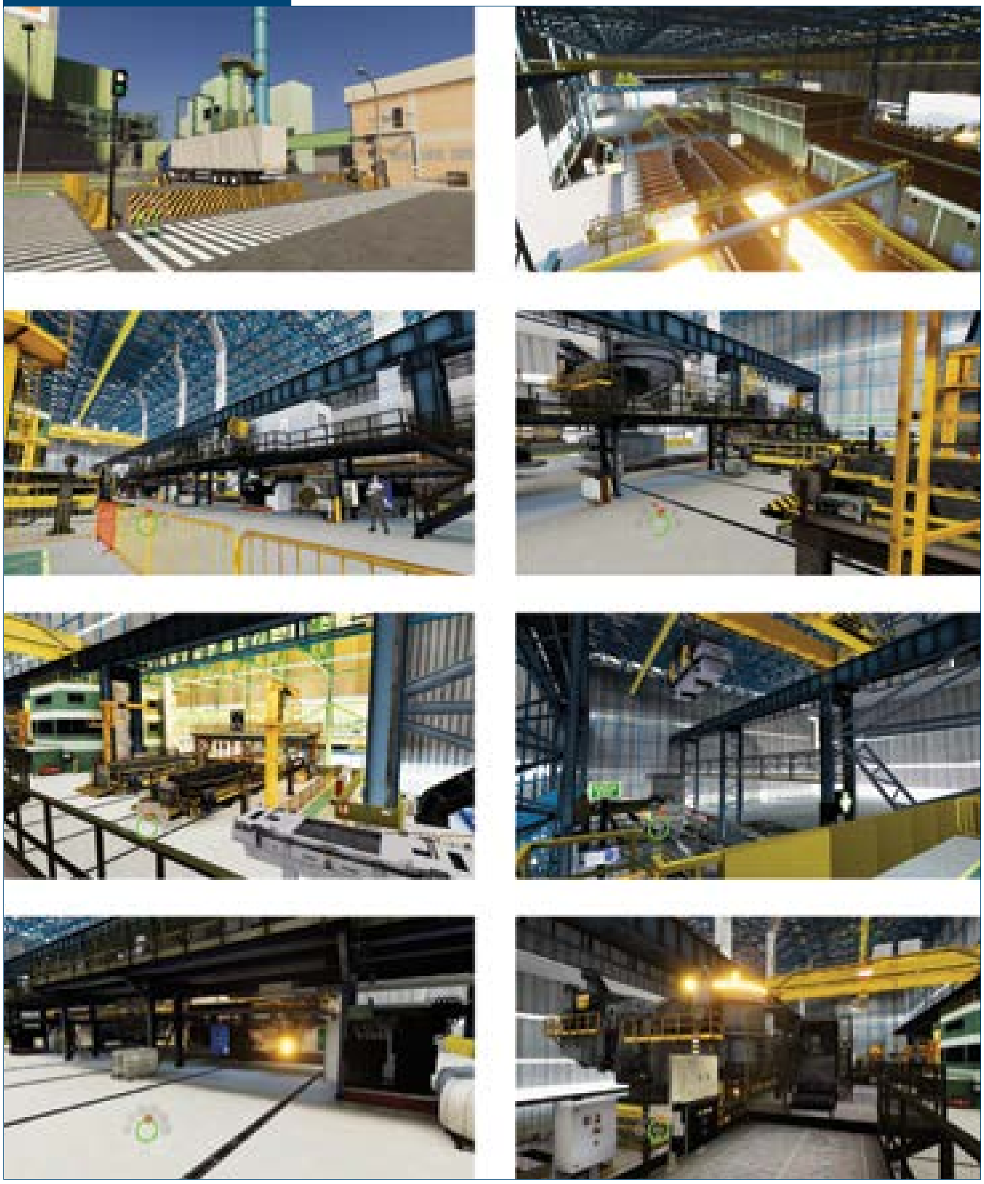
provide an even deeper submersion in the VR training experience.

As shown in the basic layout of the simulator architecture in Fig. 9, the executable allows the login as administrator or user, whereas the executable utilizes an HTTPS Representational State Transfer (REST) request in order to validate username and password at Ternium's Azure Active Directory (Azure AD). After a successful user validation, user registration data is gathered in order to generate at the end of the simulation a detailed personalized performance report including user registration number, date, simulation area, number of recognized hazards, lost lives, etc. Furthermore, the performance report is made available as evidence at Ternium University's Learn Management System (LMS) in order to provide training evidence for Ternium University and the human resources department for each participant.

When logged in as administrator, the main properties of the simulator, such as hazard types, response possibilities, icons, color schemes, etc., can be configured and modified, which allows the adjustment of the simulator without the need of contacting a system developer.

Visual impressions of the modeled simulation environment and the attention to detail are shown in Fig. 10.

Figure 10



Visual impressions of the modeled VR environment of the continuous casting area of Ternium Brasil.

per year or never had been in the steel plant before at all. Each of these groups was further divided in two subgroups, whereas the first subgroup played the VR simulation in the "secure walkway area," the other subgroup in the "operation area."

A questionnaire was handed over to each trainee at the end of the VR training session, in order to record and statistically evaluate impressions, opinions and criticism regarding the newly developed VR training method. Each question could be answered using five different degrees of agreement. Fig. 11 lists these 10 questions and the distribution of the levels of agreement.

Only 4% of the individuals reported that they felt a slight dizziness after playing the game.

Regarding enjoyment, playability, truthfulness and game immersion (Q2, Q3, Q4, Q5 respectively), over 85% of the individuals rated them positively. However, around

Implementation and Testing

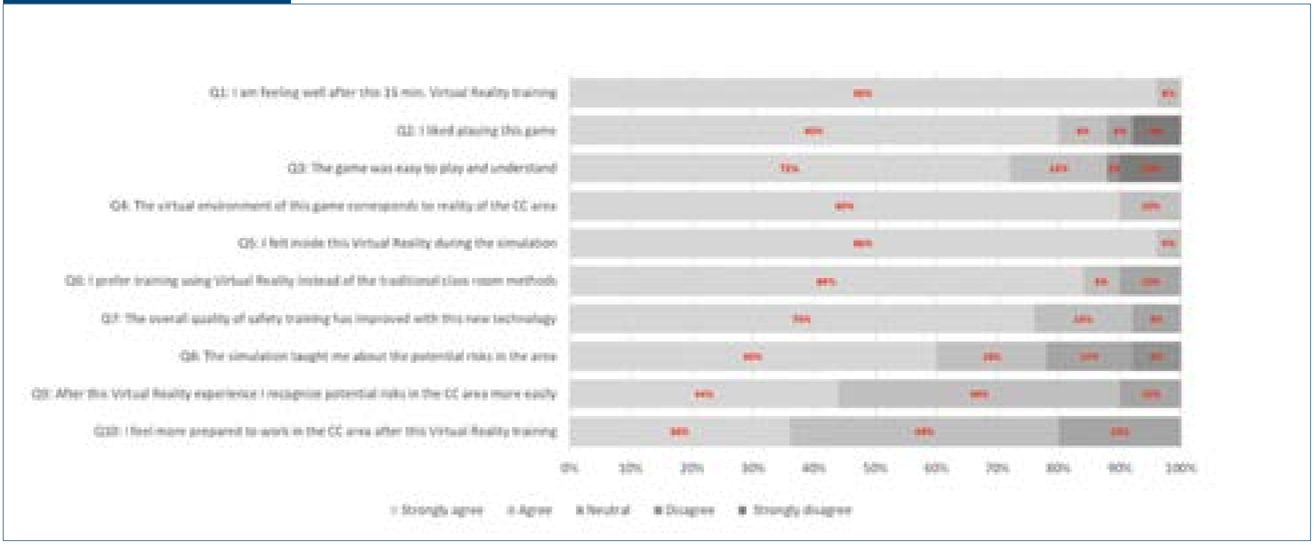
After development, the simulator hardware was installed in a dedicated training room. The hardware included a PC workstation with an 8-core processor, 8GB of DDR6 RAM, a high-end 8GB graphics card and a VR system with dual-OLED displays with a combined resolution of 2880 x 1600 pixels and high-resolution surround sound.

However, before the training system could be released for its intended use, the new training method was tested and evaluated on 100 selected individuals. One half of these individuals were very familiar with the operational area and the other half was used to visiting the operational area only a couple of times

10% of the individuals had problems regarding the interaction with the controllers and therefore experienced difficulties related to movement through the simulation area and hazard detection, which caused some frustration during playing. Due to these occurrences during the test phase, a test environment was additionally implemented inside the simulation (Fig. 12), where each player has time to familiarize themselves with the VR environment, gameplay and controller functions before entering the safety-related VR training.

Overall, 80% agreed that the game improved the actual safety training (Q6 and Q7). The majority of the individuals responded that the simulation improved their ability of recognizing potential

Figure 11



Questionnaire and the statistical outcome for measuring the users experience of the new VR safety training.

hazards in the continuous casting area (Q8 and Q9). However, 18% of the individuals responded that the simulation did not improve their ability in recognizing hazards since for them (the majority very familiar with the operational area) the hazards in the simulation were too obvious, and 80% of the individuals felt better prepared for their daily tasks in the operational area after experiencing the VR simulation.

Conversations with the test individuals revealed that due to the general popularity of games and simulators, the trainees were eager to test this new technology and see their known environment inside a simulation.

Fig. 13 shows the number of correctly recognized hazards of the test individuals, which were, as mentioned earlier, subdivided in four distinctive groups. The mean value of identified hazards for the group which was very familiar with the operational area reads for the secure walkway area 5.6 and for operational area 5.7. The mean values related to the less experienced group are significantly lower and read for the secure walkway and operational area 5.3 and 5.1, respectively.

All six possible hazards were detected by 66%, 74%, 46% and 38% of the individuals of each group. Less than four hazards were detected only by 5% of all individuals. According to Fig. 13, neither group showed a significant difference in the number of detected hazards in both simulation areas.

The distribution and the mean values of the detected hazards make it quite clear that the recognition of hazards and their avoidance has a lot to do with experience and knowledge of the operational area. This result also underlines the need and the value of this newly implemented VR safety training for those with little or no experience in the operational continuous casting area.

Figure 12

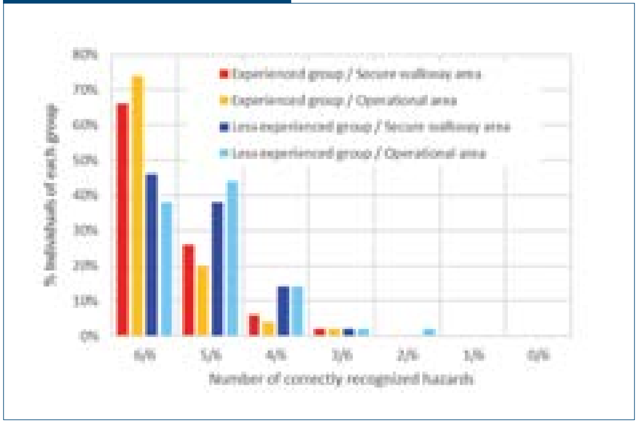
Implemented test environment of the VR simulator for familiarizing with VR environment, gameplay and controller functions.

Conclusions

This paper described the development of a hazard recognition training system of Ternium Brasil's steel plant environment in form of a serious game using Virtual Reality technology. The gameplay was set up in the way that during 15 minutes of gameplay six typical hazards need to be recognized.

The feedback of selected test individuals during the test period showed a very good reception of this new training method and proved itself as very effective in increasing the employees' ability of hazard recognition in the steel plant environment, especially for those who visited the operational area infrequently.

Figure 13



Result of the safety training during the test phase.

The test results revealed that individuals with less experience in the operational area recognized on average fewer hazards than their colleagues who frequent the operation area.

After successful tests, the system is now used on a daily basis to familiarize newly contracted or non-permanent workers with potential hazards and risks of their working environment before entering the operational area for the very first time. By incorporating this serious game for hazard recognition in the safety training program, Ternium Brasil made a step forward in improving the quality of their safety training and therefore decided as a next step to extend the coverage of the VR simulation to the whole industrial complex.

References

1. World Steel Association, “Safety and Health in the Steel Industry,” worldsteel position paper, 2020.
2. G. Carter and S.D. Smith, “Safety Hazard Identification on Construction Projects,” *Journal of Construction Engineering and Management,* Vol. 132, No. 2, 2006, pp. 197–205.
3. M. Namian, A. Albert and C.M. Zuluaga, “Role of Safety Training: Impact on Hazard Recognition and Safety Risk Perception,” *Journal of Construction Engineering and Management,* Vol. 142, No. 12, 2016.
4. T. Susi, M. Johannesson and P. Backlund, “Serious Games: An Overview,” Technical Report HS-IKI-TR-07-001, School of Humanities and Informatics, University of Skövde, Sweden.
5. I. Jeelani, A. Albert, R. Azevedo and E.J. Jaselskis, “Development and Testing of a Personalized Hazard- Recognition Training Intervention,” *Journal of Construction Engineering and Management,* Vol. 143, No. 5, 2017, pp. 04016120.
6. D. Schofield, R. Hollands and B. Denby, “Mine Safety in the Twenty-First Century: The Application of Computer Graphics and Virtual Reality,” *Mine Health and Safety Management,* ed. Michael Karmis, SME, Littleton, Colo., Chapter 10, 2001, pp. 153–174.
7. I. Jeelani, K. Han and A. Albert, “Development of Immersive Personalized Training Environment for Construction Workers,” *ASCE International Workshop on Computing in Civil Engineering 2017,* Reston, Va., USA, pp. 407–415.
8. D. Zhao and J. Lucas, “Virtual Reality Simulation for Construction Safety Promotion,” *International Journal of Injury Control and Safety Promotion,* Vol. 22, No. 1, 2015, pp. 57–67.
9. W. Lee, T. Lin, F. Castronovo and K. Lin, “Serious Games for the Learning and Practices of Hazard Recognition: Understanding the Design Complexity for 3D Construction Site Modeling,” *Journal of Computing in Civil Engineering*, 2014, pp. 2055–2062.
10. W. Westera, R.J. Nadolski, H.G. Hummel and I.G. Wopereis, “Serious Games for Higher Education: A Framework for Reducing Design Complexity,” *Journal of Computer Assisted Learning,* Vol. 24, No. 5, 2008, pp. 420–432.
11. D.R. Michael and S.L. Chen, “Serious Games: Games That Educate, Train, and Inform,” Thomson Course Technology, Boston, Mass., USA, 2006.
12. P. Van Rosmalen, R. Klemke and W. Westera, “Alleviating the Entrance to Serious Games by Exploring the Use of Commonly Available Tools,” 5*th European Conference on Games Based Learning,* Athens, Greece, 2011, pp. 613–619.
13. Q.T. Le, A. Pedro, H.C. Pham and C.S. Park, “A Virtual World Based Construction Defect Game for Interactive and Experiential Learning,” *Int. J. Eng. Educ.,* Vol. 32, pp. 457–467.
14. M.J. Burke, R.O. Salvador, K. Smith-Crowe, S. Chan-Serafin, A. Smith and S. Sonesh, “The Dread Factor: How Hazards and Safety Training Influence Learning and Performance,” *Journal of Applied Psychology,* Vol. 96, No. 1, 2011, pp. 46–70. ✦

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