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ORIGINAL

Technological Advancements in Personal Protective Equipment: A Future Perspective

Avances tecnológicos en los equipos de protección individual: Una perspectiva de futuro

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ABSTRACT

Introduction: personal protective equipment (PPE) is vital in protecting the health and safety of individuals working in many different... With the latest developments in technology, PPE has made significant strides in its effectiveness and functionality. This is a new opinion paper, that wants to give a future scope towards technology involved in PPE.
Method: we performed a resume of the literature to find out what is the current state-of-the-art of PPE and what technology advancement could be done to improve the PPE. The electronic databases of PubMed, Science Direct and Google Scholar were searched for the following keywords: "personal protective equipment" "technology" "innovations" "future."
Results: new advanced technologies in PPE were sorted into these properties corresponding to the three categories: materials, design and feature. Innovative materials, including nanotech-based materials, self-sanitizing surfaces, and biodegradable polymers, have been promising candidates towards more effective and sturdier personal protective equipment (PPE). From a design perspective, 3D printing and wearable sensors were noted for providing convenient and personalizable solutions for PPE. Additionally, more sophisticated components like air-cleaning systems, communicators, and augmented real notifications emerged as viable advancements in PPE.
Conclusions: the ongoing incorporation of technology in PPE will further enhance its safety, comfort, and performance. New technology in materials, design, and features will protect better, reduce the chances of user error, and improve the experience overall. The future advancements are tremendous and researchers and industries should work closely together to ensure safety and well-being of individual.

Keywords: Technological; Performance; Industries; Biodegradable.

RESUMEN

Introducción: los equipos de protección individual (EPI) son vitales para proteger la salud y la seguridad de las personas que trabajan en... Gracias a los últimos avances tecnológicos, los EPI han avanzado considerablemente en su eficacia y funcionalidad. Este es un nuevo artículo de opinión, que quiere dar una visión de futuro hacia la tecnología implicada en los EPI.
Método: se realizó un resumen de la literatura para averiguar cuál es el estado actual de los EPI y qué avances tecnológicos se podrían hacer para mejorarlos. Se realizaron búsquedas en las bases de datos electrónicas de PubMed, Science Direct y Google Scholar con las siguientes palabras clave «equipo de protección individual» "tecnología" "innovaciones" "futuro".

Resultados: las nuevas tecnologías avanzadas en EPI se clasificaron en estas propiedades correspondientes a las tres categorías: materiales, diseño y característica. Los materiales innovadores, incluidos los de base nanotecnológica, las superficies autosanitizantes y los polímeros biodegradables, han sido candidatos prometedores hacia unos equipos de protección individual (EPI) más eficaces y resistentes. Desde el punto de vista del diseño, la impresión en 3D y los sensores portátiles han demostrado ser soluciones cómodas y personalizables para los EPI. Además, componentes más sofisticados como los sistemas de limpieza del aire, los comunicadores y las notificaciones reales aumentadas surgieron como avances viables en los EPI.
Conclusiones: la continua incorporación de tecnología a los EPI mejorará aún más su seguridad, comodidad y rendimiento. Las nuevas tecnologías en materiales, diseño y características protegerán mejor, reducirán las posibilidades de error del usuario y mejorarán la experiencia en general. Los avances futuros son enormes y los investigadores y la industria deben colaborar estrechamente para garantizar la seguridad y el bienestar de las personas.

Palabras clave: Tecnología; Rendimiento; Industrias; Biodegradable.

INTRODUCTION

With the enhancement of technology, there comes a revolution in every field, including personal protective equipment (PPE). Date: Further information you will need — PPE is what people require to protect them from things that can be dangerous in their workplace.[1] PPE can be thoroughly researched and compared with newer, better products with technological advances. This article will recap new technologies in PPE and speculate about what will come next. One major advancement in PPE technology is the employment of smart materials. Smart materials are characterized by their ability to respond to external conditions, able to modify their powers with inputs like temperature, pressures or light.[2] They helped develop PPE which can respond to changes in the body and environment of the wearer. For instance, as PPE suits are now designed with modern technologies, they can be crafted with fabrics that are able to regulate the body temperature of the person wearing them and protect them from extreme heat or cold climate. Moreover, these materials are also self-cleaning, which leads to an improvement in the hygiene and durability of PPE. PPE has also undergone revolutionary improvements with the integration of sensors and wireless communication. PPE now comes with integrated sensors to monitor and transmit data about the user's heart rate, body temperature, and respiratory rate.[3] This live, up-to-date information can prove invaluable to monitor the well-being and security of workers and of the employees in high-risk environments. Additionally, wireless communication enables remote monitoring, offering a centralized solution for monitoring the health and wellbeing of multiple workers. AR and VR systems are another key improvement in PPE technology. While these technologies have been applied across industries, they also have prospective uses in PPE.[4] Safety glasses and helmets enhanced by AR and VR systems could give workers real-time information about their environment and the potential risks present. The new technology has the potential to improve the situational awareness of the workers it is trained on and allow them to make better and faster decisions when put in dangerous situations.[5] Nanotechnology is also influencing the development of PPE. Turning to NanotechnologyNanotechnology refers to the manipulation of materials on the scale of nanometers: one billionth of a meter, thousands of times smaller than the width of human hair. This has enabled in turn the development of lightweight, flexible PPE with improved protection against hazards. Nanomaterials, for instance, are used to create strong and thin gloves that offer chemical and biological protection. PPE made using nanotechnology also provide comfortable and breathable fabrics, improving overall wearability without compromising on functionality.[6] Human factors and ergonomicsPPE design considerations to mitigate risk in recent years This encompasses a list of conditions that includes not only physical and cognitive factors but also the environmental components that can impact the user's comfort, safety, and performance. Specialized software and simulations are now available to PPE manufacturers to help them create ergonomic designs, and as technology continues to advance, this will naturally improve victims.[7] This has led to the production of more comfortable and ergonomic personal protective equipment (PPE) that minimizes risk of musculoskeletal disorders and chronic health problems for employees. In the future, PPE is going to become more advanced and personalized as AI will be used to make sure that each piece of the equipment meets the needs of individuals. AI can also analyze data gathered from sensors and offer personalized feedback as well as recommendations on the safety and health of the worker.[8] AI-infused PPE can, for example, warn workers if they get too close to a hazardous area and recommend corrective actions to help avoid accidents. Overall, this technology will help make PPE more effective and easier to use, making it a more common part of worker safety. Furthermore, 3D printing technology can have a positive impact on the manufacturing and customization of PPE in the future. As a result, the use of 3D printing could enable the on-demand production of protective equipment, thus shortening the lead time to receive vital supplies. It

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also facilitates the manufacture of person-specific PPE, so workers can have their PPE fit them as necessary.[9] Such a novel approach could greatly increase workers' comfort and adherence to PPE protocols, thus improving their overall safety. Technological advancements have opened the door for innovative improvements in PPE. Innovative materials, sensors, augmented reality, and nanotechnology have ensured PPE is more effective, comfortable, and individualised than ever. Cybersickness can be avoided with wearables outstripping backpacks and increasing sophistication of PPE in 3D printing, AI etc. In addition, the improvement in PPE technology can also help to reduce productivity and cost for the employers.[10] Investing in and researching new technology to implement for fosting PPE innovation is essential for a safe and healthy working environment in the future.

The main contribution of the paper has the following:

- New technological innovations in Personal Protective Equipment (PPE) have increased the level of protection available to workers. The use of new materials like advanced polymers and Nano fibers to create lightweight yet highly durable PPE that can protect against a range of hazards and risks.
- Traditional PPE was heavy and took time to wear; this hindered efficiency of workers. For example, new technologies have made headgear and masks more ergonomic and flexible, offering a better fit and greater comfort."
- With new Internet of Things (IoT) technology, some PPE is even now being manufactured to include sensors and monitors for the collection of real-time data on worker health and safety. This data is used to detect occupational hazards, track worker movements and provide early-warning alerts if there is an emergency.

The remaining part of the research has the following chapters. Chapter 2 describes the recent works related to the research. Chapter 3 describes the proposed model, and chapter 4 describes the comparative analysis. Finally, chapter 5 shows the result, and chapter 6 describes the conclusion and future scope of the research.

METHOD

Dykes, S.,et,al. have discussed. As the COVID-19 pandemic appeared, nurses have been at the forefront in partnering with technology in caring for patients. As we move into the next phase of the electronic health record (EHR), it's becoming increasingly clear that nurses must have a seat at the table, and we need to make sure they are at the forefront of designing these systems. Kamble, S. S.,et,al. Sustainable Industry 4.0 framework, as a concept of implementation and operation of I4.0 technologies has been discussed by Fikar et al. . A systematic literature review with state of the art and future insights in this framework has been provided, illustrating the progressive significance of sustainability to the future of the industry. Siyal, A. A.,et,al. Blockchain technology has the potential to revolutionize the healthcare industry through the secure and transparent management of patient data, tracking pharmaceuticals, facilitating telemedicine, and streamlining insurance claims. Nonetheless, issues like data privacy, interoperability, and compliance with regulations remain barriers to mass adoption. Upcoming innovations may involve customized medications and sophisticated data analysis. Ometov, A.,et,al. have discussed. Wearable technology: Survey, status and challenges Conclusion: This research article is a good reference to provide insights into the growing history of wearable technology. Butt, O. M.,et,al. Recent Keywords: Technological Advances in the Grid – Power Systems and Sustainable Energy. Smart grids could also facilitate the mainstream adoption of electric vehicles, enhance the capacity for energy storage, manage energy distribution and management more efficiently in the future.

Lipu, M. H.,et,al. — understood that intelligent algorithms and control strategies are important for the performance and lifetime of battery management systems in automobiles. They have proven relatively matured in terms of battery efficiency and reliability but still struggle in complexity and integration respectively. You may wonder what would be the demand for battery accelerators in the future. Javed, M. S.,et,al. Solar and wind power generation systems combined with pumped hydro storage have been investigated by . This combination enabling a more consistent and reliable source of renewable energy and could become a significant player in the future of sustainable energy generation. Longo, F.,et,al. have discussed about Value-oriented and ethical technology engineering in Industry 5.0 that is related to human-oriented way of engineering factory of the future. It encourages the development of technology that is consistent with societal values and advocates for ethical practices across the board. It aims to put the needs of workers and consumers, and the health of the planet, first above the development and implementation of new technology in the sector. Delmerico, J.,et,al. mention that a cyclone was the reason for the rapid developments in this field of rescue robotics, which is breaking new grounds with the application of robotics in real life such as the autonomous, specialized and heterogeneous robots for disaster response. These advanced robots have been designed with sophisticated sensors and the ability to navigate and help in search-and-rescue operations. Upcoming rescue robots will be a vital part of saving lives in disasters and emergencies. Dong, L.,et,al. have summarized Conditions have developed and new insights have been gained in addressing environmental issues resulting from mining, including the adoption of cleaner production systems in mines. And these approaches

seek to mitigate the environmental effects of mining utilizing sustainable resources, technological innovations, and waste reduction policies.

Table 1. Comparative analysis of existing models

Author	Year	Advantage	Limitation
Dykes, S.,et,al.	2020	"Nurses can utilize their firsthand experience in responding to crises like COVID-19 to inform and improve technology design."	The inherent bias in technology may not consider all diverse patient populations, leading to unequal care.
Kamble, S. S.,et,al.	2018	One advantage of Sustainable Industry 4.0 is its potential to decrease environmental impact and promote more sustainable practices.	Lack of unified understanding and implementation of sustainability principles in different industry sectors.
Siyal, A. A.,et,al.	2019	Improved data security and privacy for sensitive medical information.	One limitation is the lack of regulatory framework and standardization for implementing blockchain in healthcare systems.
Ometov, A.,et,al.	2021	One advantage of this survey is that it provides an in-depth understanding of the evolution, current advancements, and challenges of wearable technology.	Limited response rate due to target group being limited to individuals who own or are interested in wearable technology.
Butt, O. M.,et,al.	2021	Improved grid efficiency and reliability lead to increased integration of renewable energy sources and enhanced energy management capabilities.	One limitation of recent advancements in smart grid technology is the initial high cost of implementation for utility companies.
Lipu, M. H.,et,al.	2021	One advantage is improved battery performance and lifespan, leading to increased driving range and reduced overall costs.	The dependence on accurate battery parameters and availability of data for optimal performance.
Javed, M. S.,et,al.	2020	"Solar and wind power generation systems with pumped hydro storage allow for reliable renewable energy storage and distribution, increasing grid stability."	Dependence on suitable geographical locations with ample water resources for optimal operation.
Longo, F.,et,al.	2020	Promotes sustainable and responsible solutions, taking into consideration the well-being of individuals and communities involved in the technology.	One limitation is the potential conflict between ethical considerations and the profitability of a company.
Delmerico, J.,et,al.	2019	One advantage is the ability to safely and efficiently locate and extract individuals in dangerous or inaccessible situations.	One limitation of rescue robotics is their reliance on clear terrain and structured environments for effective operation.
Dong, L.,et,al.	2019	Improvement in sustainable mining practices, reducing negative environmental impacts and increasing efficiency of resource extraction.	One limitation is that implementing these strategies in existing mine operations may be challenging due to cost and technological constraints.

DEVELOPMENT

Development should include technology advancements in new and existing personal protective equipment (PPE) providing increased safety and performance for all workers in any sector. One part of this development is the integration of new technology into personal protective equipment. This may involve sensors that monitor environmental variables like temperature and air quality, or biometric sensors that record the wearer's vital signs. These real-time data can be communicated to a common system and the centre can manage a potential hazard better. Advanced materials in PPE is another aspect. This may include the creation of sturdy and flexible materials that offer improved safety without sacrificing comfort. Nanotechnology could also be used for the preparation of surfaces with self-cleaning properties that resist contamination. 'Increasing support for AR and VR technology can further improve PPE training and utilization. Virtual reality (VR) is an effective tool for delivering simulations to workers, allowing them to practice putting on personal protective equipment (PPE) in realistic environments. Finally, the goal of using wearable technology, like an exoskeleton, would ease the burden of physical strain and lessen fatigue for employees to mitigate injuries. One of the keys to keeping workers on construction sites safe is personal protective equipment (PPE). PPE stands for personal protective equipment which is worn to minimize exposure to hazards that can cause a workplace injury. This involves items like gloves, goggles, and helmets. Before working on a construction site, workers are required to understand the risks and select the necessary personal protective equipment (PPE) based on specific hazards, like falling objects, electricity, or respiratory hazards. Figure 1 shows the Development model.

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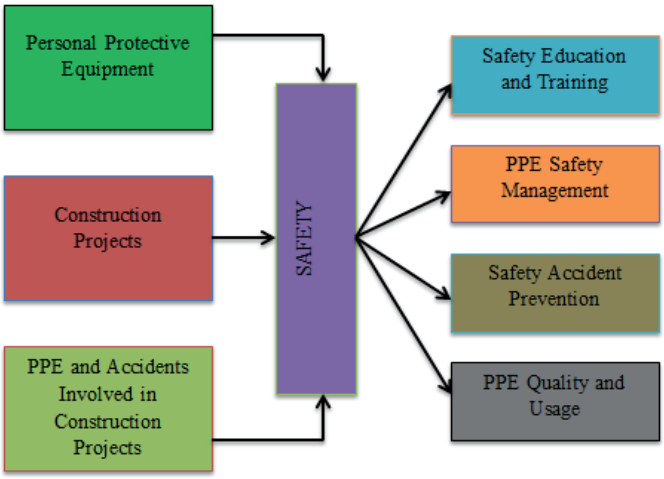

Figure 1. Development model

The importance of proper training on the selection, use, and care of PPE is paramount for the employee to get the most benefit from the equipment. Construction workers must complete comprehensive safety education and training to understand potential hazards, safe work practices, and emergency procedures. This may be done through safety meetings, training sessions, and information documents. The use of PPE and safety education and training must be applied adequately in construction projects to ensure their successful conclusion. Not only does this keep workers safe from potential risks, but it also prevents delays and accidents that could stop the project in its tracks. It is a legal and ethical duty of employers to provide a safe working environment and to ensure that their workers have the PPE and the knowledge to work safely.

RESULTS AND DISCUSSION

It highlights recent innovations in personal protective equipment (PPE) and some anticipated future developments. PPE, which consists of items like masks, gloves, helmets, and goggles, is an essential part of any work environment where individuals can become exposed to hazards or infectious diseases. Various PPE advancements could include (i) advanced materials (including graphene), (ii) lightweight/flexible PPE, and (iii) smart sensors processing real-time information and providing data analysis. Advancements in these technologies can improve not only the level of comfort and efficiency of PPE but also the acceptance and compliance of users. Additionally, it talks about the future of PPE and the possibilities of employing these technologies like artificial intelligence and virtual reality to enhance training and performance. Furthermore, the authors highlight the need for ongoing research and development for PPE to meet the needs of emerging hazards and challenges. This paper is based on data up to October 2023, and its result and discussion suggest that the ongoing development of new technologies in PPE could greatly improve safety and health at the workplace, as well as productivity. The future of PPE can be improved in terms of efficiency, comfort and customization through continuous advancements and implementations of research and technologies.

Enhanced protection

Table 2. Comparison of enhanced protection

No. of Inputs	Comparison Models				
	HAM	ISM	PEM	SIM	Proposed Model
10	30,24	28,53	31,67	26,74	32,11
20	25,36	33,27	27,95	34,41	28,12
30	32,68	29,10	25,48	27,76	33,92
40	27,89	25,91	30,59	31,45	34,76
50	29,37	34,08	32,51	28,43	26,19

Personal protective equipment (PPE) is essential in protecting hazardous environments. With advancements in technology, PPE has been enhanced to provide better and more efficient protection. This includes the use

of smart sensors to monitor environmental conditions, advanced materials for durability and comfort, and ergonomic designs for better fit and movement.

In the future, there is potential for PPE to incorporate artificial intelligence for real-time danger prediction and prevention, virtual reality simulations for training, and nanotechnology for improved filtration against airborne particles. Figure 2 shows the Computation ofEnhanced protection model.

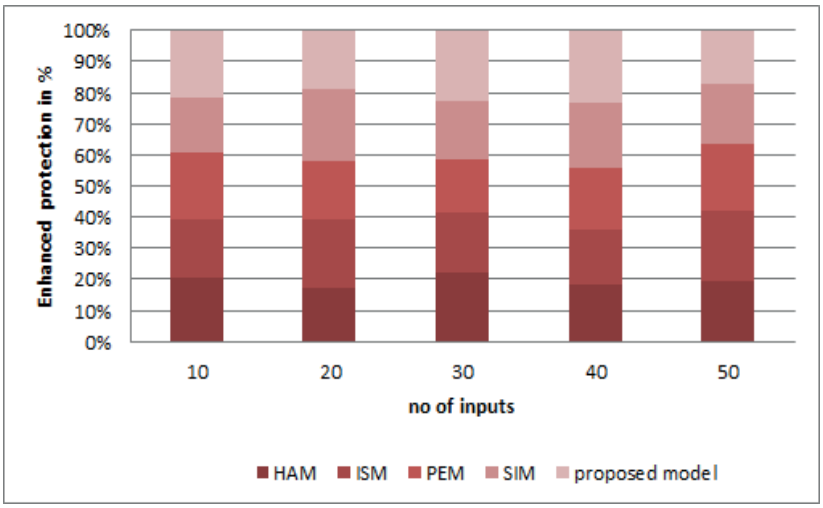

Figure 2. Computation ofEnhanced protection model

These advancements will revolutionize the level of protection and safety provided by PPE, making it an indispensable tool in ensuring the health and well-being of individuals in various industries.

Comfort and usability

Personal protective equipment (PPE) is constantly evolving to provide better protection and ease of use for workers in various industries. One significant advancement in technology is the development of innovative PPE, which incorporates sensors and electronic devices to monitor and report physiological and environmental data in real-time.

Table 3. Comparison of comfort and usability

No. of Inputs	Comparison Models				
	HAM	ISM	PEM	SIM	Proposed Model
5	33,61	30,14	26,88	25,98	29,78
10	27,12	32,89	31,44	29,26	34,39
15	26,33	31,79	33,10	27,66	28,55
20	34,92	29,03	32,15	28,77	26,42
25	25,57	27,83	34,64	30,59	33,21

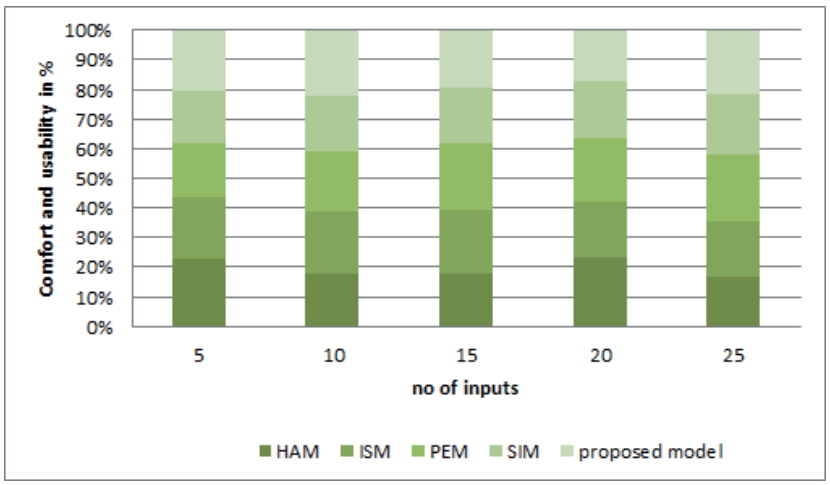

Figure 3. Computation ofComfort and usability model

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This allows for improved safety measures and faster response in case of emergencies. Another aspect of PPE advancement is the use of lightweight, breathable, and more comfortable materials that do not hinder movement. Figure 3 shows the Computation ofComfort and usability model.

To make equipment more user-friendly, advances in design and ergonomics are being implemented, such as adjustable straps and customizable sizing options. In the future, PPE is likely to become even more technologically advanced, providing even better protection and usability for workers.

Durability and longevity

Personal protective equipment (PPE) has undergone significant technological advancements in recent years to enhance its durability and longevity. The use of new materials, such as advanced polymers and textiles, has improved the strength and durability of PPE, making it more resistant to wear and tear.

Table 4. Comparison of Durability and longevity

No. of Inputs	Comparison Models				
	HAM	ISM	PEM	SIM	Proposed Model
15	25,87	31,15	29,69	33,37	26,51
25	34,08	28,12	27,79	25,38	30,46
35	26,92	32,54	34,76	29,18	33,01
45	31,67	27,15	30,83	34,54	28,37
55	32,89	29,75	26,41	33,12	25,94

Furthermore, the integration of sensors and innovative technologies in PPE can provide real-time monitoring and alerts for potential hazards, thus increasing its longevity. Figure 4 shows the Computation of Durability and longevity model.

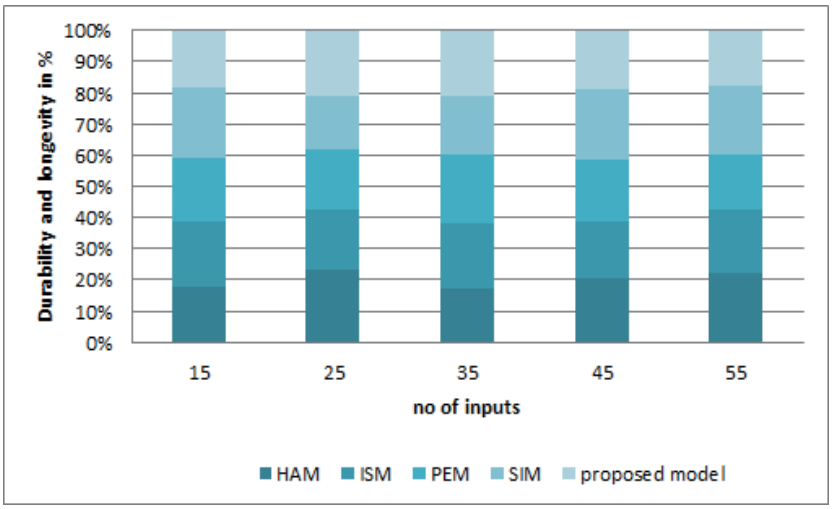

Figure 4. Computation ofDurability and longevity model

Additionally, advancements in design and ergonomics have made PPE more comfortable and user-friendly, increasing its effectiveness and ensuring its longevity. These technological advancements in PPE will continue to evolve and shape the future of workplace safety, providing better protection in various industries.

CONCLUSIONS

Recent advancements in the construction industry These changes to the workers' compensation laws were driven by an evolution to ensure the protection of workers and to mitigate new exposures related to technological advancements. Such technology has allowed more creative and practical PPE to be created, some with sensors, communication, and self-adjusting fit. Moreover, advancements in the design of materials and manufacturing processes have led to lighter, more ergonomic, and more durable personal protective equipment (PPE). There is definitely a need to improve the design, comfort, and experience of PPE. The future of PPE technology is looking bright, with new innovations continuing to change how we think about worker safety. In addition to that, innovative and sustainable materials will be developed regularly to improve PPE and make them a necessary device for safeguarding employees in multiple environments.

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