Blend of IoT and Extended Reality for Safety in Construction – Trend of Technology

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Abstract

The unprecedented challenges of fast growing cities, due to exponential increase in urban population, demands for massive housing and infrastructure projects. It is a big challenge to cater to the huge demand meeting stringent timeline and optimized economics without compromise in the high quality products. Shorter deadlines are resulting in increased fatalities at jobsite and needs immediate attention worldwide. Latest IT tools like Extended Reality (XR) applications are the solutions which will be an integral part of construction Industry. The present paper provides an insight into the Extended reality (Virtual Reality, Augmented Reality and Mixed Reality) application to prevent the Operational Safety and Health (OSH) related hazards in constructions, XR technology, working of XR, present status of research, site limitations while implementing the latest tools etc. It's an exciting time to explore new solutions for enhanced safety on construction sites, improvising the technological applications with an objective to make zero accidents (OSH) a reality at site. The digital and physical views are combined through Augmented Reality, for achieving accuracy and higher efficiency, in order to build the overall confidence in any projects. Latest IT tools advocate the use of an integrated human workforce and technology to optimise the resource consumption, contributing to the vision of the company. The technology will continue to mature and become economically feasible, while seeing increased investment and adoption. With foresightedness of identifying critical points of that field / structure and setting up sensors and camaras to capture the data, analysing the big data with references to physical environment and field conditions, makes IoT an integral part of technology even in construction field. The interaction with digital world through real and virtual world, is leading to many versions of ER and IoT is to be used integrating these two worlds with sensed data and automation of Industry. Technology enabled response system to alert the user while using hazardous materials. Similarly, creating a virtual city with existing scenario, connecting it to the real city through cloud based sensors and cameras to gather the data, analytics of big data to develop IoT applications will streamline the city planning and improves 2-D blue prints. All data points gathered from IoT helps in envision the historical repository of data which includes the infrastructures and facilities like pedestrian traffic, street traffic, lighting and other services, weather conditions so on. Industrial safety is one such area.

Key Words:
IT Applications in Construction Fields, Safety, fatalities, Indirect Effects, Emerging Technologies, Internet of Things

1. Introduction

The unprecedented challenges of various Cities are due to the pace at which there is an exponential increase in the urban population. The worldwide increase in urban population per day due to migration and/or birth is nearly 0.15million. The rise of urban population of the world from 2011 is projected to rise by 72 % by 2050. (i.e. from 3.6 billion to 6.3 billion) and the projected share of population in urban areas is increased from 52 % (2011) to 67 %(2050) [1]. This not only demands for massive housing and infrastructure projects, but also focuses on how we build and manage to provide a built environment within a short duration of the project, to improve the lives of billions of people. The latest technologies that are the solutions, will be the integral part of construction industry (in dwelling and infrastructures projects) in near future, and will also influence the working style

/ work culture of Civil Engineering Industry. Some of the emerging IT tools that are going to be the future of the industry for the construction site for enhancing the OSH -Operational Safety and Health and productivity are exceptional skills which dictates the career in the industry in future; and new materials to enhance our nation's infrastructure, that are some of the construction innovations are going to make a huge impact on the construction industry [2]. Construction safety is going to be the number one priority across all jobsites to meet various targets and completion of the project on time. Nearly 340 million occupational related accidents are reported every year around the world as per the report of International Labour Organization, with major share from construction industry in comparison with other industries [3]. At every stage of the production or constructions, industries are keen to explore all possible ways to reduce/minimise the OSH accidents on jobsites. The technology which is gaining significant investment and acceptance is Extended Reality as a tool to enhance the safety requirements and to have the control of situation in construction sites [3]

The latest trend of worldwide use of IoT based Apps which provide solutions through internet connected devices has crossed the predicted digit of number of internet connected things of 25 billion in 2021. The main working of sensing the external condition such as temperature, sound, touch etc., through sensors and actuators actuates the process through remotely controlled system to automate the task. Visualization of situation, analyzing its cause and position, providing solution if such an option is inbuilt, or creates awareness / alarms the stake holders is carried out through another technology called Data analytics.

Hence, Industries such as construction, manufacturing or others are getting revolutionized using IoT as a technology using the features of data analytics. The present paper highlights the application of ER, VR and IoT for construction field. Researchers globally are concentrating on providing instantaneous solutions of common cyber security issues of IoTs such as poor authentication controls to lack of encryption in communications.

Even in day to day life, enabling and enhancing VR application is made easy through IoTs. Various other application of IoT include enforcement of law, local security aspects, smart glasses for an individual officer who enforces the law, and also predictive maintenance application, medical application such as surgical operations etc.,

When biosensors and VR are blended tactfully, it helps in analyzing the online presence or aversion through a set of data of heartbeat, thermal data, galvanic response, brain wave etc., to predicts the behaviour and certain virtual circumstances. Similar applications are useful to construction industry in safety at workplace, implementation of building services and its working, maintenance of MEPs, structural health monitoring etc.,

2. Ongoing Constructions and IT Applications

The construction jobsites are expected to have a robotic look-a-like suits to protect the workers and autonomous machines by 2029 [4]. The workplace safety, maximized efficiency and visualizing the masterplan through the latest technology is the key to success in the Industry, which is witnessing tremendous automation in action. And with all the possibilities, the technological applications can only keep growing [4].

As technology continues to transform industrial projects in terms of its design, construction and operation, maintenance etc, even the safety at site also must evolve with it. Many advanced technologies, have developed innovative tools to augment the construction teams to achieve optimised resources deployment with the best quality of the project [5]. The merit of automation is time compression, resulting in better and quick decision, optimized design, fully mechanized construction site to reduce the risk involved in on-site and off-site related construction activities. The ultimate goal is to boost the productivity and shortening the project life cycle [6].

A Few smart construction gadgets are listed as follows [5].

a. Bluetooth Headset - For weather proof, clear and safe team communication gadget in the fields facilitating the communication for a distance up to 2 miles

b. Safety Glasses - A camera embedded, wi-fi coupled, smart safety glasses with projected screen for the construction workers to perform a specific and precise task, avoiding costly mistakes.

c. Halo-Light - A headwear for more visibility at night with a view up to quarter of a mile having 360-degree visibility, comes with a charging battery for up to 34 hours

d. Smart Clothing - A responsive clothing to provide comfort to the worker, which cools/heats based on external temperature, changes its colour if the worker wearing it comes across any toxic substances etc.

e. Smart Helmets - A specially designed, multi-tasking AR headwear with HD video recording, 360^0 navigating cameras, facilitates 3D mapping, photography, alphanumeric capture used for recoding maintenance, compliance Optimisation, data mining and much more (Fig. 1).

f. Laser Scanner - An extension over photography/video, a laser Scanner captures 3D models to the mapping and documentation there by increases the understanding, quality control, efficiency, productivity and safety as well (Fig. 1).

g. Construction Drones - The construction drones are useful from the conception of a project to its completion including maintenance of a structure, monitoring its health. The data collected through these drones are uploaded to cloud platform and stored for future access (Fig. 1).
h. Safety using AI Tools (Fig. 2).

Fig.1. AI Tools for Construction Sites [6].

Fig.2. AI and AR Applications at Construction Sites [7]

3. Safety in Construction Industry

The construction industry, one of the riskiest in terms of OHS is the second-largest industry in the world, responsible for nearly 20% of the death of workers as per the report of U.S. Dept. of Labour [8]. One major area which deviates the projects from its target is unexpected accidents in site.

3.1 Fatalities of Construction Workers

During 2018, the number of workers died on the job is 5,250, amounting to nearly 100 per week or 14 deaths per day. The data records on death by "Fatal Four" of constructions activities show 33.5% by Falls, 11.1% by Struck by object, 8.5% by Electrocutions and 5.5% Struck or Caught-in-between, which amounts to 58.6% of the death due to accidents [8]. Adoption of automation of construction sites is making a major difference [8] The death rate in America with 38 workers a day in 1970 is reduced to 14 a day in 2017 and the rate is 10.9% in 1972 reducing to 2.8% in 2017 towards injuries and illnesses.

3.2 A Brief on Safety in Construction

Safety is the control of recognised Hazards to attain an acceptable level of risk. Construction Companies are committed to protect operational safety and health of employers and other stake holders and to strive for continuous improvement in its health, safety and environmental performance. Companies are keen to act positively to prevent injury, ill health, damage and loss arising from its operations and to implement local legislation, as a basic requirement of employees and stake holders.

A. The terminology related to safety.

- **Safety** - free from risk and danger
- **Hazards** -an unsafe condition or activity, that if left uncontrolled can contribute to an accident.
- **Accidents** - An unexpected and undesirable event resulting in damage or harm.
- **Risk** - The assessment of 'probability of loss' and 'potential amount of loss'.

B. Causes of accidents may be due to the **Physical, Chemical, Biological and Ergonomic** hazards [9].

C. **Various situations like** risk of exposure **on a construction site** can result in illness, injury, permanent disability, or even death. On various types of projects around the world, there are endless configurations and fatalities in the United States, specifically in construction, is actually increasing because of several factors for such as language barriers, cultural barriers, and stigmas around immigration policy [5].

D. **Accidents may be** Major (causing death), Fatal injury (broken bones and amputation), Non-fatal injury (finger cut) and OSH accidents (MSD, hearing loss) [9].

E. **Effects of accidents in construction -** Absence from work (>1 day, > 3 days etcLoss of manpower in hour due to work-related and ill health workplace injuries, , increased accident statistics of the company, absentism, low morale etc., hampering overall performence of the project, impacting on time, budget, loass of resources and hence surfer in overall quality of the end product (project) [9].

3.3 Automation of Safety in Construction

The advanced information technology such as Artificial Intelligence (AI), Extended Reality (ExR) that is Virtual Reality (VR), Augmented Reality(AR) or Mixed Reality (MR) etc., has developed tools for construction sector in which one of the major applications is for OSH to benefits everyone at sites for safer and more productive constructions [6].

The project managers are monitoring the real time work and construction activities at jobsite through the application of AI, a latest software too which is illustrated using cameras at site, facial recognition and information about objects and people (Fig.2) [6]. The new tool helps in monitoring the performance skill of employees and their expertise to handle the equipment. The facial recognition of the AI tool will be able to recognise the worker who is in violation of policies or one who is making his surroundings accident prone area [6].

Fig.3. Safety at Construction Site [6]

The present paper provides an overview of the application of VR and AR or MR for OSH applications, specifically in construction, highlighting its merits, limitations and scope for future development.

3.4 Augmented Reality(AR) for Safety in Construction

In current workflow, safety is a separate deliverable from the daily tasks at hand-job hazard analysis. A safety card must be filled out by each and every worker before the work can begin, a permit must be granted before work can continue and reports must be filed before workers can go home as a daily routine. The technologies like VR/AR/MR, integrating safety precautions directly into workflow has made safety implementation an easier task [4]. With AR/MR systems, safety becomes the first step in any task, and something which continue to revisit throughout the day, not a separate box to check before one can start a task or report progress.

VR and AR are most capable IT tools in almost every industry sector triggering faster decision making [10]. An engaging visualization, created through AR triggers q quick decision making as the tool makes the projects look like a real time projects. Augmented Reality make the entire building process easier to handle with expected efficiency, right from the conception of a project till completion [10]. The efficacy and practicality of the project can be achieved creating an AR experiences in a fraction of the time [10]. AR is used in almost all the industries such as medical field, banking system, tourism, marketing and even the education sector for teaching learning process, machine vision and gesture recognition technologies for military applications [11]. Offices and Industrial safety is one field that provide a check on fatality rate and health hazards using AR tangibly.

3.5 Augmented Reality

The process of integration of digital information of any particular application and user's environment in real time in which the new information is overlaid on the top of real time environment is an Augmented Reality(AR). The concept was first coined in 1990 by Thomas Caudell, a Boeing researcher, with one of the first application in football game in 1998[11]. The VR creates a totally an artificial environment, whereas AR orchestrates and controls different aspects of the augmented reality experience through a computer program [4]. The interaction with the various sensors, devices, and displays is nothing but an AR application. The distinction between the AR application and the *content* is to be drawn to use AR within the application. When this distinction is executed skilfully, the same AR application can be used in many different contexts [3].

3.6 Extended Reality

The technical term used in the industry - Extended Reality (XR) refers to all superimposed real-world and immersive virtual environments, including: *Virtual Reality (VR), Assisted or Augmented Reality (AR), Mixed Reality (MR) [3].*
Virtual Reality is a platform migrated from desktop visualization model to wearable devices which allows the wearer for a 360 degree views, to provide an interactive experience in a virtual world with full body movement tracking. It includes re-positioning the and object selection options too [3].
Augmented Reality(AR) is a step forward of VR, in which wearer through smart-glasses or headsets gets a descriptive textual and visual information, with a provision of two-way video communication, a smart way workflow chat box interaction, hands-free voice data capture etc.,
A tool that provides an enhanced immersive experience merging AR and VR with the real world is Mixed Reality(MR) and the spectrum of MR is presented in Fig. 3. It uses additional resources/tools namely, data from IoT, Sensors and 2D media. MR creates a sensory realism in the real world by creating an impression of merged content in a real time.

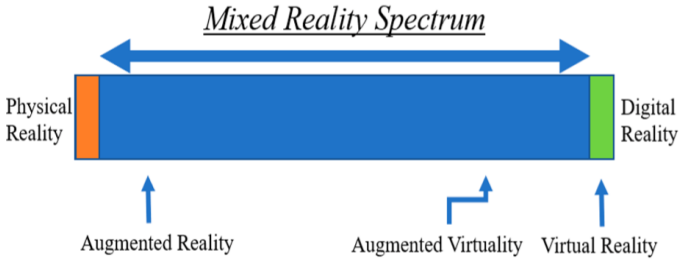

Fig.4. The Spectrum of Mixed Reality as per Milgram [12]

3.7 How AR works

AR is a two-step process, consisting of determining the current state of physical world and virtual worlds (step 1), and displaying the merger of virtual and real world to give a sense of a virtual world being a part of real world (step 2). When one cycle of two-step process is completed, the process of determining current state (step 1) repeats and proceeded further until the application is complete. Both the steps have many sub-steps and many methods or technologies can be used to implement AR, adopting these two major steps [13]. These two steps, supported by three major components of an AR system are sensors, a processor and a suitable display [13]. A sensor determines the state of physical world to deploy the application, a processor is for evaluating the data captured by sensors, and helps in implementing the laws of nature and it also drives the display, generating the signals required. The effect of coexistence of the real world and virtual world on the participant's sense, impinging upon his/her senses is created by the display Fig. 4 [13].
The sensors employed are for performing the job of tracking, collecting environmental information and also for gathering inputs. The position (location and orientation), absolute or relative is tracked with X, Y, Z, yaw, pitch and roll as six degrees of freedom, and exact location and also the orientation is tracked using Global Positioning System (GPS) [13]. The three basic types of AR technology in use are SLAM - Simultaneous Localization and Mapping, Recognition or Marker Based and Location Based [11].

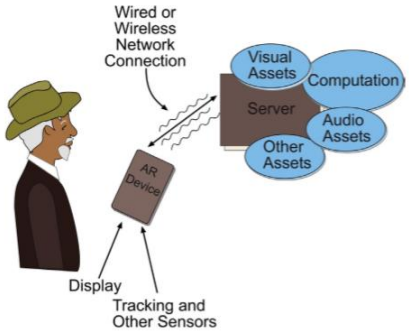

Fig.5. A server-based AR System offloads some of the burden of an AR [13]

"Improving safety" is often listed as a benefit of AR and Mixed Reality (MR) technology (Fig. 5), especially in the industrial sector. Safety is a core value of all companies in construction, energy and manufacturing and AR/MR has often supported in striving for zero injuries and fatalities [5]. From a safety perspective, application of latest software tools could be limitless in helping protect workers from injury, while industrial safety has improved remarkably over

the last 50 years [5]. In the United States, there are still 9.2 deaths for every 100,000 full-time construction workers, according to the National Census[4].

4.0 Literature Summary

The application of Extended Reality - XR (VR/AR/MR) can be traced in the literatures in various fields of OSH aspects of construction industry. They are as follows [14].

1. Safety Application objectives – Heavy equipment training, Hazard Avoidance and identification and Hazard response and communication.
2. Safety Related Purpose - Education and Training, System type, Monitoring on-site Environment and Preconstruction planning
3. Hazard Types – General safety, Fatality due to Struck-by, Caught-in, Fall, electrical (electrocution)
4. Hardware and Software Development for Safety - Peripheral Hardware and Software development for construction safety applications.
5. System Type – Virtual Reality, Augmented Reality, Augmented Virtually, Mixed Reality, Extended Reality.

4.1 Multimodal Human Computer Interaction

Multi modal Human-Computer-Interaction (HCI) refers to a sensory channel of input/output between a human and a computer. Multi-modal HCI refers to systems that enable audition, vision, gustation, olfaction, haptics, nociception, thermosception, and equilibrioception as modalities to be used as inputs/outputs. However, the variety of modalities used is still limited; The interaction focuses primarily on audition, vision, and more on haptics limiting the use of variety of modalities. [15]. The new area of intense research is Multimodal HCI which has a potential for more in-depth AR and VR systems [16].

Among the technologies falling with in the MR spectrum, VR in spite of huge computational cost time for development. and is the most dominant one. VR-MR are widely used for Education and training purpose of safety applications, and it is a tool used by many researchers for improving hazard identification skills, hazard avoidance, hazard communications and response [14]. The hazard category addressed by many researchers was struck-by and caught-in, and next is general safety and fall hazards. The VR as a tool delivers a real time environment through a 360-degree panoramic view creating a high sense of presence [17]. An inherent photographic technique used in the advanced version of 360-degree VR helps in easy to produce simulation, fast digital jobsite generation, with precise realism [17].

The training and education of workers, managers, and students on AR and VR application of the safety was the most common purpose reviewed in the literatures. The main advantage of VR and MR is to train the employees for a riskiest/dangerous filed activity through simulations which saves the workers from chaotic exposure of real time training at jobsites [7]. Because of the highly visual nature of AR/MR media, there are multiple ways of communicating hazards and safety precautions other than a direct language translation [5].

5. AR/VR/MR for Tainting Workforce in Safety

It is the need of the hour/top priority in construction industry to reduce the overall accidents' rate and fatality during construction and improve the productivity [3] adhering to a new policy of zero accident philosophy, and improve the quality of safety procedures. Training for safety is another important extension of application of AR/MR technology in which with immersive training, companies can give new employees the actual workflows they will use on the job, coupled with immersive media like 3D models and animations [5]. New Employees to get the exposure to risk in the construction industry during challenging situations using VR/AR/MR creating a situational awareness in a busy work site [5]. When new entrants or new employees are exposed to risks in a controlled environment, it helps to respond better when a hazard is encountered on the job [5]. XR is adopted most commonly in training of major activities such as crane handling, operation and maintenance [3].

A study in Applied Ergonomics found that 42% of construction site accidents occur because personnel lack knowledge of how to behave or respond [5]. By training employees in immersive environments that feel 90% "real" companies can better equip workers with hazard identification skills before they start the work [5].

The wearables or mobile devices through VR and AR applications can used to create a real time simulated view of construction site, without being present at the site, providing a 360-degree spherical view to train the workers for an expected safety precaution at a jobsite, prior to the construction. This will enable the worker to be alert highlighting a safety point of interest throughout the constructions [3]. When the real world safety problems are addressed through this technology, adoption of the technology is accelerated [3].

5.1 MR Training through Video Games on Safety

In the era of video games, OSH is used as a theme for video games in VR-MR systems and are used as the tools of education and training. The safe crane dismantling procedures were developed as a multiuser VR video game, which was used for training and practice using a Wii game controller [18]. The performance of real time experienced worker was compared with the performance of a fresh worker trained through these video games and needles to mention that fresh worker performed better than an experience worker. A VR game which is highly collaborative construction activities with in a virtual environment, developed by Guo et al. [19] was used as an effective safety training tool. Similarly, application of trench safety activities with a focus on three of 'Fatal Four'[20], hazard identification testing games [21] which are entertaining, immersive and interactive and a safety education tool to create an awareness of dangers situations of constructions [22] were also developed. The large data to be gathered from safety filed problems, data to be analysed and integrated to provide solutions using IoT applications.

5.2 Limitations, Challenges, Security, Privacy and Data Ownership Issues

The unpredictable environment of construction sites with no control over external noise pollution, humidity, dust, extreme temperatures, and other environmental concerns, make adoption of these technologies extremely difficult and potentially unsafe. There are new privacy and security matters of new IT applications and concerns of deceptive holograms, physiological attacks, inappropriate content, virtual clutter, invasive applications and bystander privacy, among others problems [23]. However, data collection through cameras and sensors combining VR and IoT provide solutions to many such situations.

6. Conclusions

Integration of digital and physical views through augmented reality is supporting construction teams drive more efficiency, accuracy, and overall confidence in their projects. Rather than replacing workers on the field, AR can be used to greatly enhance the ways humans and digital machines work together. Despite the low levels of adoption due to site challenges, there is an indication that construction companies have a high interest in investing in AR and VR technologies [24]. From eliminating errors to offering insight, augmented reality in construction can effectively streamline the entire product lifecycle[25]. The technology will continue to mature and become economically feasible, while seeing increased investment and adoption. With foresightedness of identifying critical points of that field / structure and setting up sensors and camaras to capture the data, analysing the data with references to physical environment and field conditions, makes IoT an integral part of technology even in construction field.

The technological advancement like IoT is required to be utilized for the most appropriate situations of the fields in which the seamless integration of virtual and real environment is to be made through the application of Extended Metaverse framework[26]. The potentiality of future designs for connected experiences should be through the proper synthesis of virtual and physical environments. Overall, we are in a decade which is compressed not to years but to months due to the fast changing scenario of technological developments in the areas of internet, VR, AR, ER etc. with smart interfacing that can be hyper connected, immersive and engaging.
The interaction with digital world through real and virtual world, is leading to many versions of ER and IoT is to be used integrating these two world with sensed data and automation of Industry.

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