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ASSESSMENT OF SENSOR TECHNOLOGY FOR SAFETY MANAGEMENT OF CONSTRUCTION SITES RISKS IN ONDO AND EKITI STATES, NIGERIA

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Abstract — This study examines the role of sensor technology in preventing personal, environmental, and mechanical risk factors on construction sites in Ondo and Ekiti, Nigeria. A mixed-methods approach was used, involving a questionnaire administered to 144 participants and two focus group discussions with 16 industry professionals. A pilot test established the instrument's high reliability, with a Cronbach's alpha of 0.94 overall (0.79 for PRFs, 0.84 for MRFs, and 0.82 for ERFs). Quantitative data analysis revealed a strong consensus among respondents on the critical risk factors, with mean ratings for 15 Personal Risk Factors (PRFs) ranging from 4.23 to 4.76 and 16 Environmental Risk Factors (ERFs) ranging from 3.82 to 4.46. All 19 Mechanical Risk Factors (MRFs) were also agreed upon, ranging from 3.88 to 4.55. ANOVA results showed no significant difference ($p > 0.05$) in the perceptions of architects, contractors, and site supervisors for the vast majority of factors (46 out of 50 items), indicating a unified view across professions on the need for sensor-based solutions. Thematic analysis of qualitative data enriched these findings, with participants emphasising technology's role in monitoring worker fatigue, environmental hazards, and equipment failures. This study emphasises the critical need to equip construction personnel with sensor technology, offering a proactive approach to detecting and mitigating risks. Recommendations include establishing a committee for regular safety standard updates, providing government incentives for technology adoption, offering specialised worker training, and fostering collaboration between industry, academia, and technology manufacturers.

Keywords: sensor technology, construction sites, personal risk factors, environmental risk factors, mechanical risk factors

1.0 INTRODUCTION

Technology has significantly transformed various industries, including construction, which significantly impacted a nation's physical infrastructure and economic growth trajectory over the past decade [1]. The construction industry has adopted cutting-edge technologies to strengthen its sustainable contributions [2]. The relevance of the construction sector for economic growth is central in a dynamic environment [1]. Its continued relevance depends on adaptability and technological integration, as demonstrated by computer-controlled developments that have led to process optimisations, cost savings, accelerated production timelines, raised safety standards, and significant advancements in sustainability [3]. Forecasts indicate a large increase in the use of technology in the construction industry [4]. However, there is a glaring gap in the construction industry's adoption of digital skills and technology, which impacts health and safety [5]. There are an alarming number of accidents and fatalities at construction sites, which have historically been known for their dangerous working conditions [6]. Given the devastating statistics on accidents and fatalities among construction workers [7], the adoption of sensor technology has become a compelling necessity for improving construction safety. Sensor technology has the potential to transform safety management procedures in the construction industry because it can record and translate physical, chemical, and biotic data into actionable signals [8]. Famakin et al., 2012 [9] claimed that the conventional methods of preventing hazards on construction sites primarily record accidents but frequently fall short of quantifying near-miss incidents, and flaws are made worse by the complexity of modern building projects. In view of these issues, it is therefore pertinent that this study be carried out to examine the role of sensor technology in preventing personal, environmental, and mechanical risk factors on construction sites. Specifically, the study determined the following:

1. Personal risk factors in construction sites that require safety management practices using sensor technology.
2. Environmental risk factors in construction sites that require safety management practices using sensor technology.
3. Mechanical risk factors in construction sites that require safety management practices using sensor technology

2.0 LITERATURE REVIEW

2.1. Overview of the Sensor Technology

Sensors have become essential tools in the field of technological growth for identifying changes, energy, and the flow of energy within various systems. A sensor is a device that can detect signals and react by transforming them into easily understandable outputs, frequently interacting with transducers [10]. A sensor is created to measure various intriguing parameters and then generate electrical, mechanical, optical, or computer-based output signals [11]. According to Das [12], there are two main categories of sensors: active sensors, also known as parametric sensors, which require external power sources, and passive sensors, which produce electric signals on their own and do not require external power. As stated by Zhang et al., 2017 [13], there are various types of sensor technology, including wireless sensor networks (WSN); GPS; RFID; ultra-wideband (UWB); Zigbee; ultrasound positioning systems (UIPS); and vision-based sensors.

2.2. Features of Sensor Technology

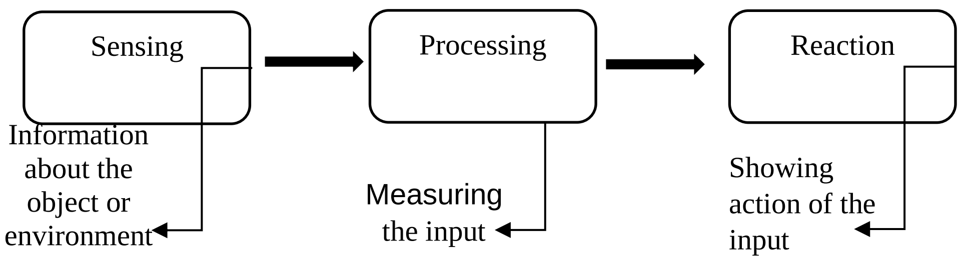

Figure 1 Features of sensor technology designed by the author (2022)

The above figure explicitly illustrates the features of sensor technology. It has sensors that gather data about an object or environment and process the input before displaying the action that was entered.

2.3. Safety Management Practices in Construction Sites in Nigeria

Construction sites are dynamic environments where various experts, including architects, contractors, quantity surveyors, structural engineers, and labourers, engage in various activities. The construction industry is unfortunately responsible for one in five occupational fatalities globally [14]. The simultaneous work of diverse experts on construction sites increases occupational risks due to their varying skill levels, knowledge bases, and work habits [15]. Over the years, there have been efforts to establish safety-management procedures on construction sites. However, the efficacy of these measures is questionable. Hon et al., 2012 [16] affirmed that safety management procedures in the construction sector are still far from ideal in many nations. Accidents continue to occur despite significant investments in safety management to reduce fatalities and property losses [17]. Although there are risks in the construction industry by nature, the focus is now on improving technical proficiency and risk awareness through preventative measures, such as training programmes and the implementation of safety protocols, to mitigate these risks effectively.

2.3. Risk Factors in Construction Sites

Risk is crucial in determining project success, particularly in construction sites, as it involves potential hazards posing threats to worker health, safety, property, and the environment [18]. Risk factors at construction sites are acts that could be dangerous, have the potential to have negative effects, and harm the health, safety, and integrity of workers, property, and the environment. These risk factors were categorised as personal, mechanical and environmental by Goh et al. [19].

2.3.1. Personal risk factors (PRFs)

Personal risk factors (PRFs) at construction sites are frequently influenced by individuals' expectations and standards regarding safety. Farooqui et al., 2008 [20] defined PRFs as unsafe activities resulting from human behaviour, ineptitude, and the management's dominant safety culture. Dangerous behaviours such as misunderstanding, forgetfulness, and overconfidence among construction workers, including underuse of PPE, can lead to harmful activities like alcohol and cannabis use [21]. Similarly, PRFs on construction sites include overconfidence, worker safety culture, lack of knowledge, improper attitudes, machine handling practices, unnecessary exposure, neglect of safety devices, and violations of regulations [22]. Additionally, Kemei et al., 2015 [23] highlighted several characteristics that are significant contributors to PRFs, including insufficient safety awareness, a lack of commitment to safety, a reluctance to engage in safety measures, and inadequate worker education. The incorporation of sensor technology is thought to be essential in preventing fatalities resulting from these risk factors, thereby improving safety management procedures on construction sites.

2.3.2. Environmental risk factors (ERFs)

Environmental risk factors (ERFs) in construction include weather, lighting, noise, contaminants, and ground features that increase accident probability unintentionally, affecting the physical and atmospheric work environments [24]. Environmental Risk Factors (ERFs) can be overt or covert, depending on site conditions such as layout, location, weather, equipment, and material quality, which pose significant environmental risks to construction workers [25]. For example, hazardous material spills, fires, explosions, gas leaks, risky activities, unsafe surroundings, and meteorological factors [26]; noise, vibration, radiation, and excessive temperature variations, both hot and cold [27]; congestion [15]; falls from heights [28]; and chemical risks from asbestos, welding fumes, spray paints, cutting oil mists, solvents, and hexavalent chromium [29] are all ERFs on construction sites. Environmental risks in construction sites include scaffolding, roofing, elevator shafts, cranes, flooring gaps, falling objects, and elevated positions, necessitating continuous oxygen level monitoring for potential hazards [30]. Additionally, chemical exposure to various materials and compounds poses health risks to workers through ingestion, inhalation, or skin contact [31]. Purohit et al., 2018 [14] reported that ERFs are dangerous situations at work that have the potential to cause harm or negative outcomes.

2.3.3. Mechanical risk factors (MRFs)

The manual or powered use of tools, equipment, machinery, and plant resources by employees is inextricably tied to mechanical risk factors at construction sites. Given its powerful capabilities, heavy machinery use is a substantial MRF that covers a wide spectrum of problems, including equipment quality, failures, inadequate maintenance, and malfunctions [26]. Accidents involving heavy machinery can result in collisions, falls, entrapments, crush injuries, and vehicle-to-vehicle accidents; workers may sustain injuries if they are unintentionally caught in moving or rotating machine parts. The risk associated with machines on construction sites is worsened by insufficient machine-guarding procedures [26]. The risks associated with MRFs include collisions with moving machinery and poor machine operating techniques. Serious injuries and fatalities may result from hazardous machining procedures and careless use of safety equipment [14]. Thus, safety management is a significant element in preventing risk and guaranteeing project success on construction sites.

3.0 MATERIALS AND METHODS

A mixed-method research design was used in this study to strategically take advantage of a comprehensive approach to data gathering, boosting the depth and dependability of the research findings as recommended by Jonker et al., 2009 [32]. This methodological decision allowed for the triangulation of data; quantitative data identified and ranked risk factors, while qualitative data provided rich, experiential context on the feasibility and perceived utility of sensor technology for managing those specific risks. The study's geographical area was Nigeria's southwest region, including Ondo and Ekiti states, to address inadequate safety management practices prevalent in these states. The quantitative population included 64 building contractors, 42 site supervisors, and 38 architects, representing a wide range of construction expertise. In addition, focus groups were held to collect qualitative information and improve comprehension of the main findings. Six architects, 6 contractors, and 4 site supervisors were among the 16 participants in each of the two focus group discussions. The talks lasted for 45 minutes, with an additional 15 minutes devoted to summarising and integrating the participants' observations to maintain the discussions' focus and coherence.

Purposive sampling procedures were used to gather a sample of 144 respondents, consisting of architects, building contractors, and site supervisors, to efficiently achieve the research objectives. The sample size is considered sufficient because it represents a significant proportion (>70%) of the identified target population in the study area. These experts were selected because of their knowledge and practical experience in the construction sector, making them qualified to offer insightful advice. To directly address the reviewer's concern, the inclusion criteria for all respondents were a minimum of 5 years of professional experience in the Nigerian construction industry, direct involvement in safety management on construction projects, and demonstrable familiarity with modern construction technologies, including sensor-based applications (e.g., through prior use, training, or detailed knowledge of their capabilities). This stringent criterion ensures that respondents possessed the necessary validity to opine on whether sensor technology is an appropriate management tool for the identified risks.

A standardised questionnaire and focus group discussion guide were carefully used in the data collection process. The questionnaire, divided into two sections, collected demographic data and measured PRFs, MRFs and ERFs on construction sites that require safety management practices using sensor technology and a 5-point Likert scale. Five specialists in Ondo and Ekiti States provided evaluation and input for instrument validation. A pilot test was conducted to evaluate the instrument's reliability using Cronbach’s alpha. The results indicated that the instrument's overall coefficient was 0.94, with coefficients of 0.79 for PRFs, 0.84 for MRFs, and 0.82 for ERFs. The dependability and applicability of the instrument for this investigation were confirmed by these coefficients.

Data analysis included both descriptive and inferential methods. Descriptive statistics, specifically mean and standard deviation, were used to answer the research questions. The results allowed responses to be categorised as "Agreed" for mean scores of 3.50 and higher and "Disagreed" for mean scores below 3.50. The hypotheses were analysed using ANOVA. Additionally, a thematic approach was rigorously used to assess the qualitative data gathered from focus group discussions. This involved transcribing the discussions, generating initial codes, and identifying overarching themes related to the viability, benefits, and challenges of implementing sensor technology for the risk factors identified quantitatively. This qualitative component is crucial, as it provides the "how" and "why" behind the quantitative ratings, showcasing the expert reasoning of the participants and directly validating their opinions.

4.0 RESULTS AND DISCUSSION

Table 1 Mean Responses of the Respondents on the PRFs on Construction Sites that Require Safety Management Practices Using Sensor Technology

		N= 121		
SN	**Item statement**	**X**	**SD**	**Remarks**
1	Workers’ low or high heart rates (pulse), which could result in fatigue, dizziness, shortness of breath, sudden cardiac arrest, fainting and acute coronary syndrome.	4.74	0.49	SA
2	Workers' respiratory rate, i.e., breathing rate	4.62	0.67	SA
3	Workers' body temperature	4.50	0.75	SA
4	High or low blood pressure of workers	4.41	0.82	A
5	Workers' body acceleration on the jobsite, i.e., motion, speed	4.74	0.68	SA
6	Worker’s perspiration rate	4.40	0.89	A
7	Work pressure on workers such as overpressure or underpressure	4.23	0.76	A
8	Workers' psychological conditions, such as emotions	4.61	0.93	SA
9	Drowsiness of workers as a result of hard drugs or drunkenness	4.76	0.59	SA
10	Workers' work posture, i.e., body posture, body rotation or orientation	4.50	0.91	SA
11	Workers' improper use of personal protective equipment (PPE)	4.36	0.97	A
12	Human error such as mistakes, slips and lapses	4.58	0.74	SA
13	Improper material handling by workers	4.46	0.84	A
14	Stress level of workers on site	4.45	0.96	A
15	Workers' incorrect work procedure or operation	4.44	1.06	A

Note: X = Mean responses, SD = Standard Deviation, N = Number of respondents

Table 1 quantitatively analysed PRFs on construction sites. Notably, with mean ratings ranging from 4.23 to 4.76, respondents strongly agreed with 7 out of the 15 identified risk factors. Eight risk factors were also found to have agreement, with mean values between 4.23 and 4.46. The standard deviations (SD) for these items were also within the range of 0.49 to 1.06, indicating a degree of coherence in respondents' perceptions.

From the focus group discussions, participants identified several PRFs in construction sites that require safety management practices using sensor technology as below:

> One personal risk element that comes to my mind is lack of worker awareness of and training in safety procedures. Real-time input can be provided by sensor technologies to help monitor and track personnel' adherence to safety procedures (Participant A, Architect).
>
> Personal risk factors can include being too tired or having trouble focusing. Sensor technology can recognise indicators of exhaustion, such as heart rate or eye movement monitoring, and inform both the employee and supervisors to take the appropriate breaks or corrective action (Participant B, Contractor).
>
> On construction sites, human error is a significant problem; incorporating sensor technology may reduce errors by sending out reminders or cautions based on the activities or positioning of the workers. It's like we have additional eyes watching out for us (Participant C, Site Supervisor).
>
> Personal protection equipment (PPE) misuse can sometimes be dangerous. By monitoring the use of PPE by employees and notifying them if they are not wearing the required safety equipment, sensor technology can ensure compliance. That's a straightforward but efficient method of boosting safety (Participant D, Architect).
>
> It is crucial to keep track of employees' physical and mental wellness. Sensors can monitor vital signs and spot any potential health problems that can jeopardise workers' safety on the job site. Taking care of our team (Participant E, Contractor)
>
> Personal risk can be raised by actions like hurrying or taking with the use of sensor technology, managers can intervene and encourage safer work practices by getting information on the behaviour of their employees. The goal is to alter the workplace culture (Participant F, Site Supervisor).

The focus group discussion with construction industry professionals in Ondo and Ekiti states provided valuable insights into PRFs on construction sites, emphasising the need for safety management practices using sensor technology.

Table 2 quantitatively analysed ERFs on construction sites. Notably, the mean values range from 3.82 to 4.46, indicating that all 16 identified ERFs require safety management methods using sensor technology. The standard deviations (SD), which range from 0.69 to 1.02, emphasise how uniform the respondents' opinions are.

From the focus group discussions, participants identified several ERFs in construction sites that require safety management practices using sensor technology as below:

> The quality of the air and dust are two important environmental risk factors. Workers at construction sites may be exposed to harmful levels of dust and other particulate matter. Real-time air quality monitoring is possible thanks to sensor technology, which also allows for quick corrective action (Participant G, Architect).
>
> On building sites, noise pollution is a serious concern as well. Long-term exposure to loud noises can cause hearing loss and other medical problems. When noise levels reach acceptable levels, sensor technologies can continuously monitor them and send out notifications (Participant H, Contractor).
>
> Heavy machinery and equipment vibrations can have an impact on neighbouring buildings' structural integrity, as well as worker comfort. To avoid potential structural damage, sensor technologies can monitor vibrations and deliver real-time feedback (Participant I, Site Supervisor).

Handling numerous chemicals and dangerous materials is common at construction sites. Workers could be at risk from dangers like hazardous gases or chemicals. To ensure that personnel are not exposed to toxic substances, sensor technologies can be utilised to detect and monitor chemical exposure levels (Participant J, Architect).

Whether hot or cold, extreme temperatures can be harmful to a worker's health. Temperature monitoring equipment can warn staff members and managers when conditions deteriorate (Participant K, Contractor).

Hazardous situations can develop on building sites as a result of weather conditions like thunderstorms or strong winds. The safe evacuation of personnel is made possible by sensor technology, which can provide real-time weather updates and issue warnings for adverse weather (Participant L, Architect).

Water accumulation on construction sites increases the risk of slip and fall accidents, equipment damage, and project delays. To prevent flooding, sensor technologies can monitor water levels and drainage systems (Participant M, Contractor).

Table 2 Mean Responses of the Respondents on the ERFs in Construction Sites that Require Safety Management Practices Using Sensor Technology

N= 121

SN	Item statement	X	SD	Remarks
16	Mere drizzle/snow which can obstruct working at height	4.41	0.69	A
17	Wind conditions such as strong wind, which can limit workers' functionality on site	3.99	0.74	A
18	Heavy rainfall, which can limit workers' concentration on site	4.18	0.84	A
19	Fog, i.e., mist clouding the surface which can limit workers' visibility in site	3.82	0.91	A
20	Toxic atmosphere which could occur as a result of congested work area on the construction site	4.21	0.89	A
21	Natural occurrences such as tremor and floods	4.02	0.87	A
22	Construction site trench risks such as collapse, low oxygen, hazardous fumes	4.10	0.99	A
23	Excavation risks such as falls, cave-ins and asphyxiation	4.11	0.90	A
24	Compressed air environment, which could occur as a result of working in confined spaces such as sewers and tunnels	4.07	0.94	A
25	Possible causes of explosion such as fire, smoke or gas leaks	4.01	0.95	A
26	Bearing or position, such as when working at height, i.e., on a rooftop or ladder top, which can result a fall	4.19	0.91	A
27	Structural or construction defects such as consolidation of concrete	3.91	1.02	A
28	Manhandling of pollutants/flammables such as improper disposal of containers after use	4.16	0.90	A
29	Instability arising from temporary structures such as bracing, scaffolding, framework and formwork on construction site which could result to collapse, falls or even death	4.46	0.67	A
30	Poor ventilation or illumination that can be caused by fumes, improper exhaust from plants and tripping on site	4.05	0.78	A
31	Abnormal change of noise from plants	4.03	0.89	A

Note: X = Mean responses, SD = Standard Deviation, N = Number of respondents

These participant insights do, in fact, illustrate the complexity of environmental risk issues at construction sites. As a result of its ability to continuously monitor and mitigate these environmental risks in real time, sensor technology is required for improving safety management measures.

Table 3 data showed that all the 19 MRFs with means ranging from 3.88 to 4.32 were agreed upon. Additionally, the table showed that the standard deviations (SD) of the items were within the range of 0.53 to 1.16, indicating that the respondents' opinions were quite close to one another.

Table 3 Mean Responses of the Respondents on the MRFs in Construction Sites that Require Safety Management Practices Using Sensor Technology

N= 121

SN	Item statement	X	SD	Remarks
32	Working with/around heavy machines	4.55	0.53	SA
33	Hazardous arrangement of mechanical devices	4.02	0.68	A
34	Improper machine handling	4.32	0.73	A
35	Improper machine operation	4.07	0.86	A
36	Mechanical malfunction/breakdown	4.24	0.81	A
37	Deficiency in plant, equipment or tools, such as oil contamination or leakage	4.19	0.84	A
38	Faulty mechanical devices	4.22	0.74	A
39	Moving vehicles on the construction site	4.06	0.92	A
40	Blind spots or areas of limited visibility in red zones	4.23	0.80	A
41	Proximity range indication of machine to other objects	4.07	0.85	A
42	Rotating parts of machines which can result to grips or injuries of workers	4.22	0.88	A
43	Defective exhaust system of machine	4.10	0.89	A
44	Overloading of mechanical devices	4.10	0.88	A
45	Overturning of mechanical devices	4.14	0.77	A
46	Machine vibration conditions such as wear and looseness	4.20	0.73	A
47	Possible electric shock from mechanical devices	4.10	0.86	A
48	Using wrong tool/machines for job not meant for it	4.11	1.00	A
49	Using blunt or dull cutting tools	3.88	1.16	A
50	Unusual noise in a working machine/plant	3.95	1.05	A

Note: X = Mean responses, SD = Standard Deviation, N = Number of respondents

The findings from the focus groups highlighted a few MRFs on construction sites and how sensor technology can be used to address and manage them.

> Equipment failure is one of the major mechanical risk factors that instantly comes to mind. On construction sites, we rely largely on numerous tools and machinery, and any malfunction can be extremely dangerous. Here, sensor technology may prove essential by offering real-time monitoring to spot equipment failure warning indications before they materialize (Architect, Participant N)
>
> I concur entirely. Accidents and delays may result from equipment faults. The issue of accidents involving large machinery is another. These are frequently disastrous. With the use of sensor technology, we can keep an eye on how this equipment is moving and alert it to potential collisions or risky working circumstances (Contractor, Participant O).
>
> Another issue is inadequate equipment upkeep. Inadequate maintenance can make equipment and tools unsafe. Sensors might monitor maintenance schedules and notify us when something requires maintenance or repair (Participant P, Site Supervisor).
>
> Additionally, I would want to list vibration and noise as danger factors. Long-term exposure to loud noises and vibrations can be harmful to a worker's health. With the use of sensor technology, we could continuously inspect for unsafe noise and vibration levels (Participant F, Site Supervisor).
>
> Not to mention, extremes in temperature. Workplace health issues may result from working in high heat or cold. We might use sensors to track the temperature and prevent prolonged worker exposure to risky situations (Participant E, Contractor).
>
> Chemical dangers are another issue that worries me. Chemicals like welding fumes and asbestos are sometimes present on construction sites. Continuous monitoring for these dangerous compounds could be provided by sensor technology, protecting workers (architect, participant J).

The insights acquired from the focus group interviews shed light on the MRFs on construction sites that call for safety management practices using sensor technologies.

4.1. Hypothesis 1

Significant difference does not exist in the mean responses of architects, building contractors and site supervisors on the personal risk factors in construction sites that require safety management practices using sensor technology.

Table 4 Analysis of Variance (ANOVA) of Respondents' Responses on the PRFs in Construction Sites that Require Safety Management Practices Using Sensor Technology

SN	Item statement	F	Sig.	Remarks
1	Workers' low or high heart rate (pulse), which could result in fatigue, dizziness, shortness of breath, sudden cardiac arrest, fainting and acute coronary syndrome.	3.23	0.043	S
2	Workers' respiratory rate, i.e., breathing rate	0.232	0.793	NS
3	Workers' body temperature	2.17	0.119	NS
4	High or low blood pressure of workers	1.297	0.277	NS
5	Workers' body acceleration on the jobsite, i.e., motion and speed	0.571	0.566	NS
6	Worker's perspiration rate	0.3	0.741	NS
7	Work pressure on workers such as overpressure or underpressure	0.144	0.866	NS
8	Workers' psychological conditions, such as emotions	2.027	0.136	NS
9	Drowsiness of workers as a result of hard drugs or drunkenness	0.765	0.468	NS
10	Workers' work posture, i.e., body posture, body rotation or orientation	1.517	0.224	NS
11	Workers' improper use of personal protective equipment (PPE)	1.515	0.224	NS
12	Human error such as mistakes, slips and lapses	0.855	0.428	NS
13	Improper material handling by workers	1.235	0.294	NS
14	Stress level of workers on site	4.08	0.019	S
15	Workers' incorrect work procedure or operation	1.277	0.283	NS

Note: F = ANOVA; Sig. = Significance

Data in Table 4 showed that items 1 and 14 had significant values below the 0.05 level of significance, at 0.043 and 0.019, respectively. This suggests that the respondents' mean responses to PRFs at construction sites that require safety management practices using sensor technology varied significantly from one another. Therefore, for those items, the null hypothesis of no significant difference was rejected. Items 2 to 13 had significant values (0.119 to 0.866) above the 0.05 significance level used to test the hypothesis. Therefore, hypothesis 1 is accepted.

4.2. Hypothesis 2

A significant difference does not exist in the mean responses of architects, building contractors and site supervisors on the environmental risk factors in construction sites that require safety management practices using sensor technology.

Table 5 Analysis of Variance (ANOVA) of Respondents' Responses on the ERFs in Construction Sites that Require Safety Management Practices Using Sensor Technology

SN	Item statement	F	Sig.	Remarks
16	Mere drizzle/snow which can obstruct working at height	0.485	0.617	NS
17	Wind conditions such as strong wind, which can limit workers' functionality on site	1.216	0.300	NS
18	Heavy rainfall, which can limit workers' concentration on-site	5.867	0.004	S
19	Fog, i.e., mist clouding the surface which can limit workers' visibility in site	0.265	0.768	NS
20	Toxic atmosphere, which could occur as a result of congested work area on the construction site	1.557	0.215	NS
21	Natural occurrences such as tremor and floods	1.678	0.191	NS
22	Construction site trench risks such as collapse, low oxygen, hazardous fumes	1.066	0.348	NS
23	Excavation risks such as falls, cave-ins and asphyxiation	0.580	0.561	NS
24	Compressed air environment, which could occur as a result of working in confined spaces such as sewers and tunnels	0.641	0.529	NS
25	Possible causes of explosion such as fire, smoke or gas leaks	0.739	0.480	NS
26	Bearing or position, such as when working at height, i.e., on a rooftop or ladder top, which can result a fall	0.054	0.948	NS
27	Structural or construction defects such as consolidation of concrete	2.173	0.118	NS

Table 5 Cont'd

SN	Item statement	F	Sig.	Remarks
28	Manhandling of pollutants/flammables such as improper disposal of containers after use	0.278	0.758	NS
29	Instability arising from temporary structures such as bracing, scaffolding, framework and formwork in construction sites, which could result to collapse, falls or even death	0.952	0.389	NS
30	Poor ventilation or illumination that can be caused by fumes, improper exhaust from plants and tripping on site	0.156	0.856	NS
31	Abnormal change of noise from plants	0.698	0.500	NS

Note: F = ANOVA; Sig. = Significance

Table 5 showed that item 18 has a significance value of 0.004, which is less than the p-value of the 0.05 level of significance. This suggests that the mean response of respondents on the ERFs on building sites that require safety management practices using sensor technology differs significantly from one another. Therefore, hypothesis 3 is rejected. The significant value ranged from 0.118 to 0.948, which is greater than 0.05, established as the level of significance for testing the hypothesis, for items 16 to 17 and 19 to 31. Therefore, hypothesis 3 is accepted.

4.3. Hypothesis 3

Significant differences do not exist in the mean responses of architects, building contractors, and site supervisors to mechanical risk factors in construction sites that require safety management practices using sensor technology.

Table 6 Analysis of Variance (ANOVA) of Respondents' Responses on the MRFs in Construction Sites that Require Safety Management Practices using Sensor Technology

SN	Item statement	F	Sig.	Remarks
32	Working with/around heavy machines	0.580	0.561	NS
33	Hazardous arrangement of mechanical devices	0.882	0.416	NS
34	Improper machine handling	0.193	0.824	NS
35	Improper machine operation	0.601	0.550	NS
36	Mechanical malfunction/breakdown	0.351	0.705	NS
37	Deficiency in plant, equipment or tools, such as oil contamination or leakage	0.790	0.456	NS
38	Faulty mechanical devices	1.394	0.252	NS
39	Moving vehicles on the construction site	1.725	0.183	NS
40	Blind spots or areas of limited visibility in red zones	1.105	0.334	NS
41	Proximity range indication of machine to other objects	1.958	0.146	NS
42	Rotating parts of machines which can result in grips or injuries of workers	0.529	0.591	NS
43	Defective exhaust system of machine	0.070	0.932	NS
44	Overloading of mechanical devices	0.537	0.586	NS
45	Overturning of mechanical devices	0.365	0.695	NS
46	Machine vibration conditions such as wear and looseness	0.590	0.556	NS
47	Possible electric shock from mechanical devices	0.561	0.572	NS
48	Using wrong tool/machines for a job not meant for it	1.744	0.179	NS
49	Using blunt or dull cutting tools	0.016	0.984	NS
50	Unusual noise in a working machine/plant	1.479	0.232	NS

Note: F = ANOVA; Sig. = Significance

Data shown in Table 6 revealed that each of the 19 items has a significance value ranging from 0.146 to 0.984, which is greater than the 0.05 level of significance. This indicates that there were no significant differences between the mean responses of the respondents on the MRFs on construction sites that require safety management measures using sensor technology. Therefore, hypothesis 3 is upheld.

The study's findings show that safety management procedures incorporating sensor technologies are required for all 15 PRFs on construction sites. This highlights the necessity of incorporating sensor technologies to successfully reduce construction hazards. The study's findings are consistent with earlier research [33], which highlights the importance of sensor technologies in tracking people's physiological parameters, including heart rate, body temperature, blood pressure, blood oxygen saturation, posture, and physical activities at work. Similar to this, wearable sensors and machine learning algorithms can identify stress signals in human heart rate signals, demonstrating their potential to assess PRFs and remotely monitor worker safety [34]. Additionally, Arabshashi et al., 2021 [35] underlined the capacity of sensor technology to detect risky actions of workers. According to these conclusions, the findings of this study show that every one of the 15 PRFs that were identified causes accidents on building construction sites, which justifies the use of sensor technology for safety management. Two instances of a significant difference in mean replies were found in items 1 and 14 from the statistical analysis. However, the study rejected the hypothesis for items 1 and 14 since the p-values were lower than the planned significance level of 0.05. The study showed no significant differences in the mean responses of the respondents for 12 items.

The study's findings also demonstrate the necessity of safety management procedures utilising sensor technologies for each of the 16 ERFs at construction sites. This supports previous studies by Riaz et al., 2017 [36, 37] that emphasised that sensor technology such as Ultra-Wideband (UWB) and wireless sensor networks (WSN) are useful in managing environmental conditions like confined spaces, gas leaks, fires, or smoke leaks. Similarly, Microsystem 2011 [11] emphasised the importance of sensor technology in monitoring ERFs such as weather and geological occurrences, contaminants, and noise in the workplace that may have an impact on employees' health and wellbeing. The mean responses for 15 items did not differ significantly, according to statistical analysis of the responses. The p-value for item 18 was below the predetermined significance level of 0.05, so the hypothesis that there was no significant difference for the 15 items was accepted. However, a significant difference was seen in the mean response of item 18, which led to the rejection of the hypothesis for item 18. These results underline the importance of implementing sensor technologies on construction sites to improve safety and solve environmental issues.

The study's conclusions show that all 19 MRFs on construction sites require safety management practices using sensor technology. These findings are congruent with studies by Ibrahim et al., 2014 [38], who propose the adoption of wireless sensor network (WSN) technology to reduce machinery accidents, and Park et al., 2015 [39], who emphasise the importance of sensor technologies for monitoring dangerous zones and dimly illuminated places, including the Internet of Things, location-tracking gadgets, and Bluetooth Low Energy (BLE). Similarly, Arabshashi et al., 2021 [35] provides additional support for these conclusions, stating that sensor technology can be used to solve MRFs such as accidents, collisions, proximity detection, and vehicle and worker control. Similar to this, Abd El-Karim et al., 2017 [26] identify MRFs that call for sensing devices for safety management in the workplace, including poor equipment quality, equipment breakdown, poor equipment maintenance, equipment malfunctions, and machinery overloading/overturning. Because the p-values for these items were higher than the planned significance level of 0.05, statistical analysis of the responses did not find any statistically significant differences between the mean responses of the respondents for 19 items. This shows that the results are not statistically significant and that the null hypothesis is not challenged. Therefore, the study recommends that sensor technology be widely used in the construction sector to provide workers with a safe working environment.

The findings from the focus groups stressed the danger posed by workers' insufficient safety training and awareness. They proposed that sensor technology might be essential in observing and tracking employees' adherence to safety procedures, giving immediate feedback, and guaranteeing that all employees are properly taught. This is consistent with the study of Wu M et al., 2019 [33], which stresses the use of sensors to track the movements and actions of workers. Critical risk factors such as exhaustion and inability to concentrate have been identified. Participants emphasised how sensors may be used to track eye movements or heart rates to look for signs of exhaustion. Both employees and managers might be warned to take the appropriate breaks or corrective action when weariness is detected. The results of Choi et al., 2017 [34], which emphasise the use of wearable sensing devices for identifying physiological signs related to stress, are consistent with this. Participants stated that by sending cautions or reminders depending on workers' movements or positions, adding sensor technology could help minimise errors. This strategy is consistent with Setz et al., 2010 [40], who emphasises the ability of sensor technologies to detect stress levels and mistakes made by people.

Participants acknowledged that there could be risks associated with using personal protective equipment (PPE) improperly. They proposed using sensor technology to monitor worker PPE usage and notify them if they are not wearing the required safety equipment to assure compliance. This viewpoint is consistent with studies by Arabshashi et al., 2021 [35], which emphasise the possible use of sensor technologies to identify unsafe worker actions. Participants emphasised the significance of keeping tabs on employees' physical and mental well-being. On construction sites, sensors can be used to monitor workers' vital signs and look for any potential health problems that would endanger their safety. This is consistent with other research showing the use of sensors in keeping track of employees' health and wellbeing [35]. Personal risk was found to be influenced by behavioural elements like hurrying or cutting corners. Participants proposed that sensor technology might offer information on employee behaviour, allowing managers to step in and encourage safer work habits. This view is consistent with studies that highlight the use of sensors to track employees' behaviour [35].

Participants were aware of the dangers of gas leaks and cramped areas on building sites. In line with research supporting the use of sensors like Ultra-Wideband (UWB) and wireless sensor networks (WSN) for safety management in such contexts [36], they stressed the significance of continuous monitoring using sensor technology to detect gas leaks immediately. Participants in the discussion highlighted the importance of sensor technologies, such as smoke detectors and heat sensors, in early detection and prevention of fires and smoke on building sites. This viewpoint is in line with studies that emphasise the value of sensors and WSN for the management of fire and smoke risks [41]. Smoke and toxic substances were mentioned as environmental contaminants that could pose concerns. In line with research on sensor technologies for monitoring environmental pollutants and dangers [37], participants suggested sensors for monitoring pollutant levels to protect worker health. Humidity, temperature, powerful winds, rainfall, and fog were all recognised as important risk factors. Participants talked about how crucial sensors are for keeping track of weather conditions and providing workers up-to-date information. Their finding is consistent with a recent study [11] that highlights the importance of sensors in monitoring weather-related dangers. Participants were aware of the risks posed by construction sites' machinery.

In line with the conclusions of Ibrahim et al., 2014 [38], they proposed that sensor technologies, such as wireless sensor networks (WSN), could prevent accidents involving workers and large machinery. The need for proximity detection and control for personnel and vehicles was highlighted. Similarly, sensor technology, such as the Internet of Things (IoT) and location tracking devices, was regarded as essential for monitoring dangerous zones and places with restricted visibility [39]. Poor equipment maintenance, breakdowns, and overloading were identified as mechanical risk factors. Participants stressed the potential for sensing devices to improve safety management by identifying and resolving these problems, supporting the research of [26]. Risks associated with noise, particularly those near large machinery, were considered. The use of sensor technologies was deemed advantageous for warning employees of dangerous noise levels. This is consistent with research that emphasises the use of sensors to warn staff members about potentially dangerous proximity circumstances [39]. In fact, the responses from the participants highlight the crucial role that sensor technology plays in regulating personal, environmental, and mechanical risk factors on construction sites in Ondo and Ekiti. States.

5.0 CONCLUSION AND RECOMMENDATION

To address personal, environmental, and mechanical risk concerns on construction sites, the study highlights the necessity of safety management practices using sensor technologies, especially in Ondo and Ekiti States, Nigeria. Through the incorporation of sensor technology, it is possible to overcome the shortcomings of conventional safety management training and proactively identify and reduce threats to construction workers and the environment. To achieve the highest level of safety in the construction industry, construction workers must become knowledgeable about and proficient in sensor technology. This change will raise awareness and encourage sensor technology's widespread use as a tool for safety management. Conclusively, the incorporation of sensor technology is not only a need but also a preference for the contemporary construction sector. It is an essential part of a safe safety management system that complies with international standards. Based on the findings of the study, the following are recommended.

1. The construction industry should collaborate with educational institutions to create and provide specialised training programmes on sensor technology applications for safety management.
2. Financial incentives should be provided by governments to encourage construction companies to use sensor technology for safety management, such as tax credits, subsidies, or grants.
3. Create a committee of specialists from the industry, academics, and safety professionals to examine and update safety requirements for sensor technologies in construction on a regular basis.
4. Promote cooperation between construction firms, academic institutions, and manufacturers of sensor technology to create cutting-edge sensor solutions for construction industry safety.

6.0 IMPLICATION OF THE STUDY

The study's conclusions highlight the potential for sensor technologies to greatly improve safety at construction sites. The frequency of accidents, injuries, and fatalities in the construction sector can be significantly reduced by implementing safety management procedures based on sensor technology. Construction sites in Ondo and Ekiti States and elsewhere can better comply with these regulations by using sensor technology, creating a safer working environment for everyone. Additionally, not only can sensor technology increase safety, but it may also increase the effectiveness and productivity of construction projects. Sensor-based systems can minimise expensive delays and interruptions by recognising and managing hazards in real time, which will ultimately result in more effective construction operations. The study's conclusions are relevant outside of Ondo and Ekiti States due to the importance of safety in the construction industry on a global scale.

7.0 LIMITATIONS OF THE STUDY

The study's geographical concentration on construction sites in Ondo and Ekiti States poses one restriction. The results might not be transferable to other areas or nations with differing settings, laws, and safety procedures. Additionally, the study did not look at the long-term effects of sensor technology on safety management, indicating the need for additional research to determine how successful it will remain over time. Despite these drawbacks, the study offers insightful viewpoints from construction experts' perspectives on safety management strategies for sensor technologies. Future studies can solve these drawbacks and offer a more thorough grasp of the subject.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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