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SMART Technologies that Influence Construction Health & Safety Factors Risk Reduction in The Current Digital Era

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Abstract

Purpose – This article aims to highlight the factors affecting health and safety (H&S) and the SMART Technologies (ST) used to mitigate them in the Construction Industry through a range of selected papers to encourage readers and potential audiences to consider the need for intelligent technologies to minimise the risks of injuries, illnesses, and severe harm in the construction industry.

Design/Methodology/approach – This paper adopts a double systematic literature review (SLR) to analyse studies investigating the factors affecting H&S and the ST in the construction industry using databases such as Google Scholar, Scopus, Science Direct, and Emerald Insight publication.

Findings – The SLR identified "fatal or focus five factors" that include objects Fall from heights (FFH) and trapped between objects; Falls, Trips, and slips (FTS); Machinery/Equipment Malfunction and Moving Equipment; Pollutants: Chemicals, Airborne Dust, Asbestos; and Electrocution. The ST includes Safety Boots/SMART Glasses/SMART Helmet/SMART Vests/SMART PPE/SMART Watch, Mobile Apps, Building Information Modelling (BIM), Virtual Reality/Augmented Reality (VR/AR), Drones/ Unmanned Aerial Vehicles, and Wearable Technology/Mobile Sensors help mitigate the risk posed by "Fatal five". However, other factors within the scope of ST, such as Weather Conditions, Vibrations, Violence, Disease and illness, Fire and Explosion, and Over Exertion, are yet to be adopted in the field.

Originality/Value- This paper highlights all factors affecting H&S and ST that help mitigate associated risks and identifies the "Fatal five" factors. The paper is the first to highlight the factors affecting H&S combined with ST in use and their interactions. The paper also identified factors within the ST scope that are yet to be explored.

Practical and Theoretical implications: This article unravels the construction H&S factors and their interlinks with ST, which would aid industry understanding and focus on mitigating associated risks. The article highlights the Fatal five and trivial 15, which would help better understand the causes of the H&S risks. Further, the paper discusses ST's connectivity, which would aid the organisation's overall H&S management. The practical and theoretical implications include a better understanding of all factors that affect H&S and ST available to help mitigate concerns. The operating managers could use the ST to reduce H&S risks at every construction process stage. This article on H&S and ST and relationships can theorise that the Construction industry is more likely to identify clear root causes of H&S and ST usage than previously. The theoretical implications include enhanced understanding for academics on H&S factors, ST, and gaps in ST concerning H&S, which can be expanded to provide new insights into existing knowledge.

Keywords- Construction, H&S, Construction Risk, ST, SMART construction, Construction H&S

1. Introduction

The construction industry significantly contributes to UN sustainability Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. The construction industry, a key player in economic growth, aids in growing any country's economy (Nawi et al., 2016), investing nearly $10 trillion annually in goods and services related to construction (Awolusi et al., 2018). Despite being crucial to economic expansion, the construction industry is precarious due to its hazards and unpredictability (Ghodrati et al., 2018), with a high rate of injury and mortality worldwide (Ghodrati et al., 2018). It is concerning that the industry has yet to address H&S effectively. Even the UN sustainability program, a crucial global initiative, does not address Industrial H&S concerns. The closest it comes is target 3.9, which states, "By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination." The target 3.6 States, "By 2020, halve the number of global deaths and injuries from road traffic accidents". However, it has not yet addressed Industrial accidents.

The New Zealand (NZ) WORKSAFE department report highlights that between September 2020 and August 2021, 561 Construction-related injuries, illnesses and severe harm cases were recorded, making the construction industry the most dangerous in NZ (WorkSafe New Zealand, 2021). Construction employees actively participating in the construction process were at a greater mortality risk than individuals working in other fields (Abas et al., 2016). The nature of the construction industry has led to significant inefficiencies in project performance, with construction-related injuries causing project completion delays, increased project costs, decreased productivity, and the development of passive organisational perceptions. These statistics underscore the urgent need for safety improvements in the construction industry. Figure 1 shows NZ's industries with the highest injuries, illnesses, and severe harm (WORKSAFE, 2021).

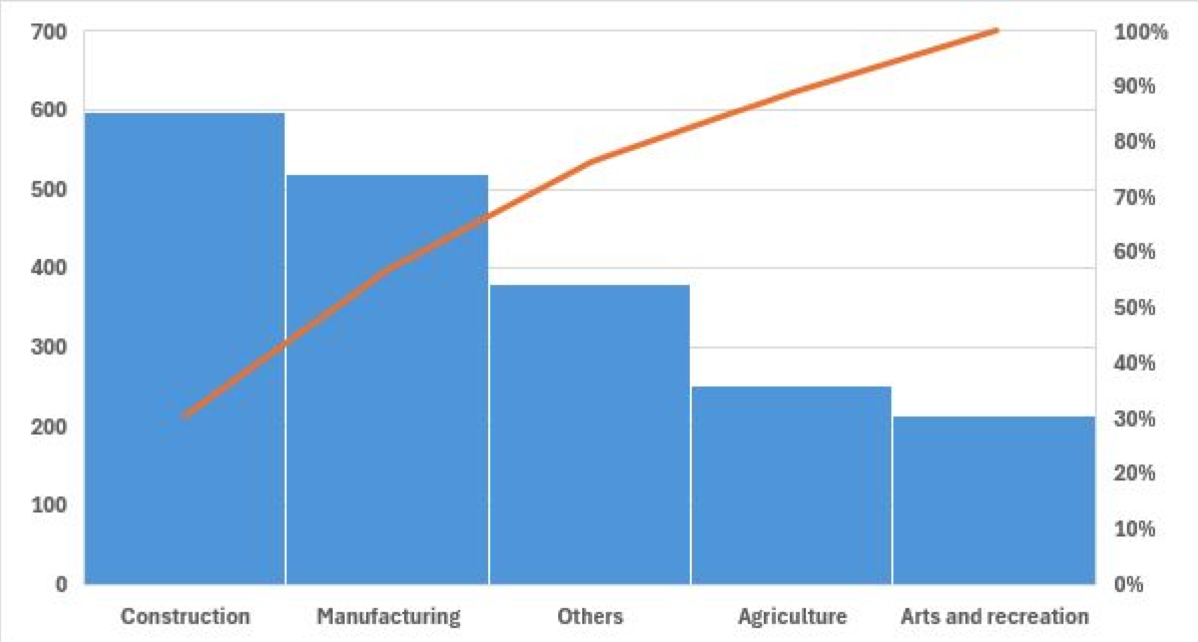

Figure 1: Industries with the highest numbers of injuries, illnesses and severe harm Source: Authors own work

BigRentz (2022) states that 1,061 people lost their lives while doing their jobs in 2019 alone, and there were more than 195,600 incidents of on-the-job injuries. Construction sites account for one-fifth of worker fatalities in the US, making it the fourth most fatality-prone sector (B.L.S, 2022). Also, Ali et al. (2017) report for the Department of Occupational Safety and Health (DOSH) in Malaysia states that the construction industry in 2017 had the most workplace accidents by sector, with 15 deaths out of 70. The frequency of occurrences affecting workplace safety and health that ended in harm or death over the last five years ending 2014 has substantially increased (Chong & Low, 2014). Large construction projects in New York have exposed workers to hazardous conditions, increasing the risk of accidents and degrading the safety performance of the projects (Chong & Low, 2014). Nadhin et al. (2016) reported that falls are the leading cause of serious injuries (48%) and fatalities (30%) of all construction accidents. FFH represent over one-third of construction injuries, leading causes of multi-serious injuries and fatalities. In 2013, FFH accounted for 36.9% of occupational fatalities in the United States, 31% in the United Kingdom, and 12% in Australia. In 2019, 50.1% of deaths across all industrial sectors were caused by FFH, being struck by an object, and collisions occurred on construction sites in Korea (Kim et al., 2020). 41.2% of these fatalities were found to be head injuries. Even though most workers on construction sites know how necessary the safety helmet is, approximately 60% of them do not wear it correctly or refuse to wear it because of discomfort, leading to injuries and fatalities (Kim et al., 2020).

The construction industry is a significant source of employment in New Zealand and contributes more than 6% to the country's GDP Hall et al. (2022). However, due to its large size, it also has a significant share of work-related accidents and illnesses. In 2020, Stats NZ reported 34,404 claims within the sector, highlighting the importance of H&S in construction (Stats NZ, 2021). According to Kim et al. (2020), FFH resulted in 300,000 injuries and 818 fatalities in the United States in 2014, making it the second-highest cause of occupational accidents. Smith (2024) reports that FFH accounts for one-third of all construction-related accidents in the United States. From 2011 to 2016, fatalities caused by FFH increased by 26%. In Great Britain, FFH was responsible for 40 out of 147 construction site fatalities between 2018 and 2019, making it the highest fatality rate in construction sites. Similarly, New Zealand also experiences a significant number of falls from height. Figure 2 shows the FFH incidents in New Zealand between Jul 2022 and Jun 2023.

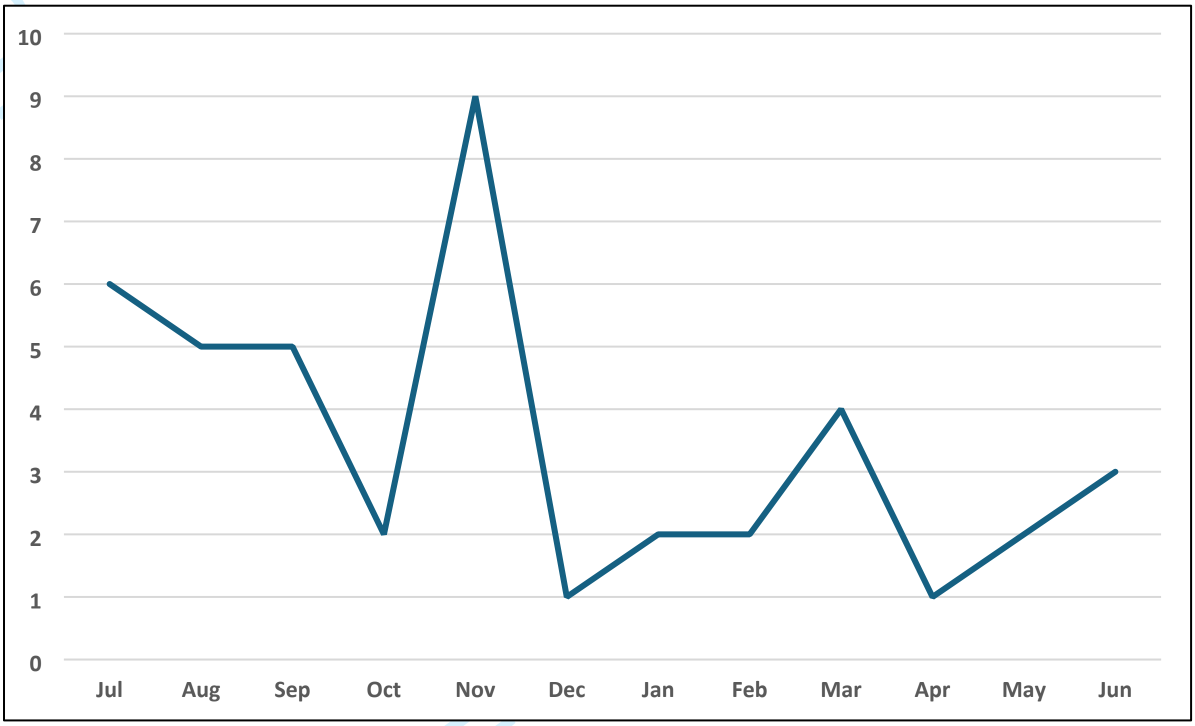

Figure 2: FFH (WorkSafe NZ, 2023) Source: Authors own work

Furthermore, according to Worksafe (2021), asbestos-related diseases claim more than 200 NZers' lives yearly, a significant concern that needs to be addressed (Lessing et al., 2017). H&S is the responsibility of employers and employees, and organisations exist to ensure the safety and health of employees (Edgar et al., 2017; Peace, 2017). Construction accident causes are influenced by the industry's unique working processes, human behaviour, unsafe work practices, equipment, and procedures. These factors contribute to poor safety management (Charehzehi & Ahankoob, 2012); employers must equip their employees with the necessary skills and knowledge, continually increasing safety standards in building projects to mitigate potential dangers. There are many human factors, such as negligence, failure to obey work procedures, failure to use personal protective equipment (PPE) (Nawi et al., 2016) and physical factors, such as equipment without safety devices, poor site management, harsh work operation (Shamsuddin et al., 2015) that leads H&S hazards. These factors could lead to accidents, further delaying work and reducing productivity (Mohammadi et al., 2018b). Therefore, every business must provide rigorous training and safety procedures (Charehzehi & Ahankoob, 2012) that may continually increase safety standards in building projects to mitigate potential dangers. Hence, workplace safety and health must be addressed to avoid accidents (Abas et al., 2020), probably correlating to the latest technologies. It is crucial to evaluate the level of safety among all people who work at the site, which is constantly impacted by many circumstances (Brauer, 2022).

Various governments across the globe have legislations that aim to protect workers' H&S. For example, according to BRANZ, the H&S at Work Act (HSWA) of NZ requires that: "All businesses, regardless of size, engage their staff in safety issues. The Act focuses on managing critical risks and taking actions that reduce workplace harm" (HSWA, 2015). Before they escalate, this proactive approach to managing risks should reassure the audience. If improvements are to be made, the safety of the building industry in NZ must be given substantial consideration. Therefore, the importance of H&S can be summed up as a government initiative to enforce the awareness of the risks associated with the construction and implement the appropriate precautions to prevent deaths and decrease injuries. The NZ government has imposed legislation, such as the Control of Substances Hazardous to Health regulations, agencies, and regulatory authorities, such as MBIE and Work Safe, to ensure that H&S measures are monitored and carried out in the workplace. This is because this industry is particularly prone to accidents and injuries. All H&S regulations and guidelines in NZ are based on the H&S at Work Act (HSWA) 2015; this act is intended to provide a balanced framework for safeguarding the H&S of workers and workplaces (Dabee, 2020). According to WorkSafe NZ, the H&S at Work Act 2015 sets out the purpose of HSWA (WorkSafe NZ, 2019). The introduction of the HSWA was a statutory requirement for designers to bring stakeholders into the equation through the mitigation of H&S risks from the cradle to the grave, known as Safety in Design (Guo & Li, 2021).

A proper H&S system has numerous advantages, such as fewer accidents, less damage to property, less downtime, better morale, better interactions amongst workers, more productivity, cheaper costs, and better quality (Vincoli, 2024). Other benefits include lower insurance costs, fewer hidden expenditures, excellent supervisor morale, productivity, and improved marketability (Cooney, 2016). Kuta et al. (2021) reported that research by the European Foundation for the Improvement of Living and Working Conditions in Dublin found that the social costs associated with fewer employee musculoskeletal disorders equal around 15% of the costs associated with workplace accidents. It should be emphasised that around 33% of manual workers in the European Union experience back and spinal pain, nearly 23% of respondents report feeling generally tired, and roughly 13% experience hand overload (Kuta et al., 2021). In contrast to other professions, the pressure on the musculoskeletal system may be 16% higher in construction environments (Kuta et al., 2021).

The International Labour Organization (2005) estimated that at least 60,000 fatal accidents occur on construction sites yearly. However, numerous studies and reports prove that safety management effectively reduces construction death and injury rates and substantially benefits society and enterprises. The casualties from these accidents result in significant economic losses to the community. For instance, the International Labour Organization (2005) reported that construction accidents account for 4% of the global Gross Domestic Product. These accidents also impact the economies of countries that use advanced safety management. However, enterprises can be particularly interested in the fact that they can effectively enhance their economic benefits by adopting reasonable safety management methods. They reported that almost half of the companies showed that improving safety management decreased the project schedule by at least one week; approximately 73% of the companies successfully reduced their total investment by 1% to 5% (Harvey, 2013). However, despite efforts, the situation has remained mostly the same since 2005. The Office of National Statistics (2020) of the UK published that the cost of injury only reached 16.2 billion pounds in 2018, accounting for 1% of the GDP in the UK. Despite the ongoing challenges, the economic benefits of safety management are clear.

When accidents occur at construction sites, developers and construction parties often suffer varying losses (Yoon et al., 2013). These losses typically fall into direct and indirect costs (Haupt & Pillay, 2016). It is important to remember that the effects of these accidents can be long-lasting, and understanding the costs involved is crucial for our industry. Haupt and Pillay (2016) stated that direct costs refer to the expenses incurred from treating injuries, and indirect costs are hidden. Most of the time, the insurable costs associated with injuries are the ones the general public knows. Medical bills, premiums for compensation benefits, liabilities, and property damage are examples of direct cost expenditures (Vincoli, 2024). Direct costs are usually calculable with reasonable accuracy (Vincoli, 2024). Understanding the importance of indirect costs resulting from accidents is crucial. They are more difficult to calculate than direct costs, consisting of all non-insurable expenditures incurred by accident (Haupt & Pillay, 2016). Often referred to as "hidden costs," these expenses are not readily apparent and do not have a good history.

Further, the increased risk of injury at work compromises employees' integrity and concerns their families at home. Construction-related fatalities and injuries have had a negative social impact, disrupted work and negatively impacted employee morale, performance, and output Y. Kang et al. (2017). There is also the lengthy process of psychological and emotional support required afterwards. By formalizing safety processes and regulations, workers must be protected against dangers of falling, such as those caused by gaps in the structure that are present either permanently or temporarily or by using unstable materials that do not provide adequate support (Choi et al., 2019). The role of policymakers becomes crucial as they enact and enforce regulations that ensure the safety of workers. Mechanisms for preventing falls have been built into the structure since the 1990s. For example, railing supports and connectors for security wires are created in Australia as a structural system component (Lingard, Cooke, Blismas, et al., 2013). Workers would be more likely to install scaffolds and link safety wires if such facilities existed. However, the accidents and incidents have not fallen to a reasonable level.

Post 2010, various researchers have identified technologies that could assist H&S in the Construction Industry in the new digital era. Multiple studies have aimed to develop cutting-edge technologies and innovative autonomous construction safety surveillance methodologies. Any definition of "SMART building technology" relates to adopting innovations, i.e., healthy, affordable, safe, and comfortable human habitation at all life cycle stages of construction projects (Khlaponin et al., 2020). "Self-Monitoring Analysis and Reporting Technology" is abbreviated as "SMART." In the real world, this technology combines the Internet of Things with artificial intelligence, machine learning, and big data to give real-world devices cognitive awareness (Liu et al., 2017). The development of SMART technology as a wearable provides a channel for results-oriented data collection and analysis (Adjiski et al., 2019). ST has been utilized recently on construction sites to reduce the number of fatalities and injuries brought on by accidents and keep track of unreported incidents (Forat et al., 2021). SMART technology is increasingly being recognized for raising safety standards in the building industry.
Any item can be connected and used as a hub for gathering or transmitting information to a more extensive

network under the IoT paradigm, centring on the interconnection of devices or "things" (Miller, 2015; Svertoka et al., 2021). However, some SMART devices can function well without user contact (Svertoka et al., 2021). For SMART gadgets to operate, network connectivity is necessary as the gadget may occasionally join a network and share data with other devices. Silverio-Fernandez et al. (2018) state that a SMART device can be considered a context-aware electronic device capable of autonomous computation and connecting to other devices wired or wirelessly for data exchange. The world is rapidly evolving and increasingly using ST due to exponential innovation in computing hardware, communication software, and technical applications (Edirisinghe,2019). This paradigm shift has occurred from mobile computing to pervasive computing to ST with embedded intelligence (Edirisinghe, 2019). This review aims to identify and examine the critical variables affecting H&S in the construction sector and mitigate the risks using innovative technologies. The review worked on the Research question:

How does the ST influence H&S factors' risk reduction in the current digital era in the construction industry?

2. Method

SLR is adopted to answer the research question. An SLR methodology has positives and limitations. Based on pre-specified eligibility criteria, SLR helps identify, evaluate, and answer a specific research question by amalgamating all the empirical evidence (Creswell and Creswell (2023). SLR is not location-dependent and primarily uses online resources. Secondly, online SLR helps researchers refine the search as much as required. The process used was similar to Pedrini and Laura (2019). The SLR had inclusion and exclusion criteria, as listed in Table 1.

Table 1 Inclusion and exclusion criteria.

Inclusion Criteria	**Exclusion Criteria**
Construction: Discipline: Engineering, Subdiscipline: Building Construction	Not in construction
H&S in construction	Not in H&S
Risk, accident, or injury in construction	Not related to risk, accident, or injury in construction
Prevention of risk, accident, or injury in Construction	Not related to the prevention of risk, accident, or injury in construction
ST in construction H&S	Not related to ST in construction H&S
ST in the prevention of H&S Risk, accident, or injury	Not related to ST in the prevention of H&S Risk, accident, or injury
Written in English	Written in languages other than English
Major databases	Small databases
Academic articles	Websites and pages

Source: Authors own work

PRISMA checklist-based SLR has been carried out for this research. Relevant past literature has been gathered from five domains that included databases of Google Scholar, ScienceDirect, Scopus, and publisher Emerald Insight using two keyword combinations to identify the factors affecting H&S in the construction industry and the ST to mitigate the identified H&S risks. The three databases are chosen due to their credibility and popularity. Emerald Insight publication was added to the search due to its diversity and credibility in publications. Significant time was spent reading and analysing articles, reviewing, structuring, and writing, and published articles were updated periodically. The SLR aims for sufficient coverage of specified topics and concepts; the researchers regularly discuss the topics and contents to be included and excluded with their colleagues from Architecture, Engineering, Construction and Projects and incorporate their suggestions. Organisation-linked Google Scholar, Emerald, Science Direct, and Scopus search gave access to many articles globally and helped follow the newest publications in construction H&S and ST. The occurrence of keywords showed that many connections could be derived from reading the articles and understanding the factors. Though no protocol was prepared for the review, keywords were used for the search. The keywords used and search results are shown in Table 2.

Table 2: Literature search results

	Selection Criteria	
Databases	**Without filters**	**Discipline: Engineering Subdiscipline: Building Construction Year: from 2012**
Keyword Combination 1	**TITLE-ABS-KEY ("construction" AND "H&S" OR "H&S" AND "risk" OR "accident" OR "injury")**	
Scopus	271	148
Emerald Insight	1743	58
ScienceDirect	443	31
Google Scholar	1450	94
Keyword Combination 2	**TITLE-ABS-KEY ("construction" AND "H&S" OR "H&S" AND "risk" OR "accident" OR "injury" AND "prevention" AND "SMART technology")**	
Scopus	134	16
Emerald Insight	255	34
ScienceDirect	365	30
Google Scholar	585	65

Source: Authors own work

After the critical steps of literature identification, screening, and eligibility, 147 papers were selected for the factors affecting the H&S in the construction and 87 papers for the ST. Figure 3 shows the method of literature selection for the factors affecting H&S in the construction industry. Review articles have been excluded to maintain originality.

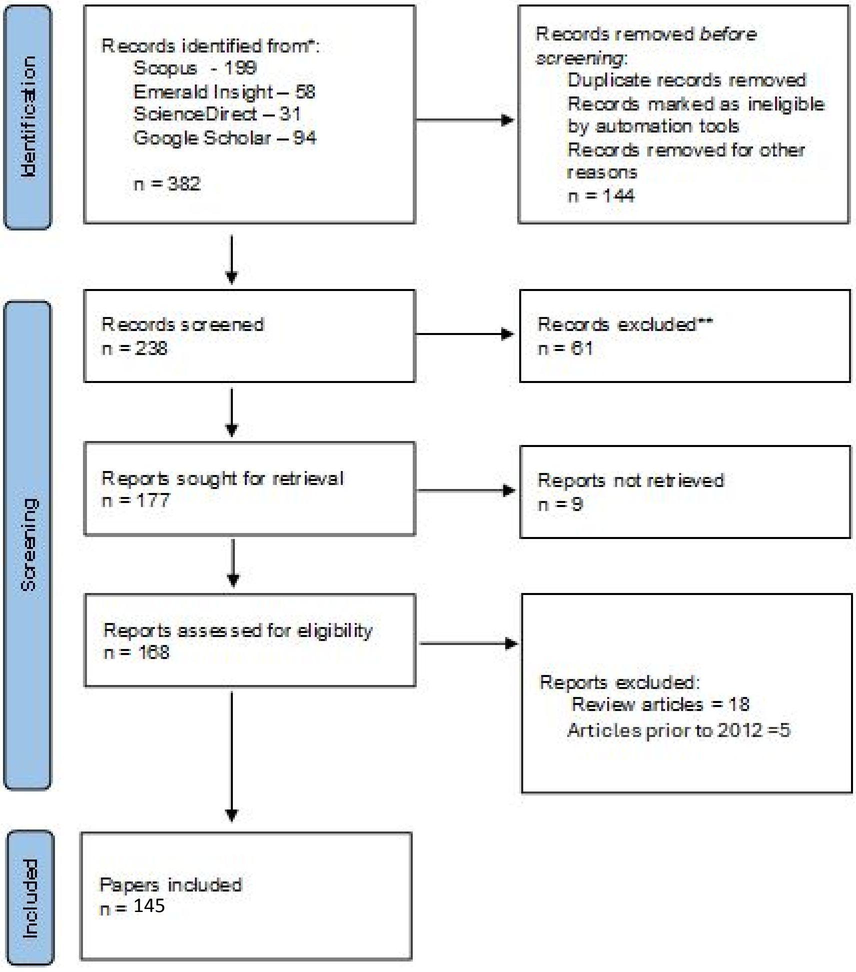

Figure 3: Identification of studies via database search Source: Authors own work based on Prisma guidelines

Articles published from 2012 to 2021 were searched using four popular databases; each was last searched on December 17, 2022. Though the investigation was from 2012, a few articles of prominence pre-2016 appeared on the list. Subsequent searches for years 2022, 2023 and 2024 during August 2024 yielded six more articles of relevance. Figure 4 shows the number of articles per year, and Figure 5 shows the visualization of H&S articles published based on the countries.

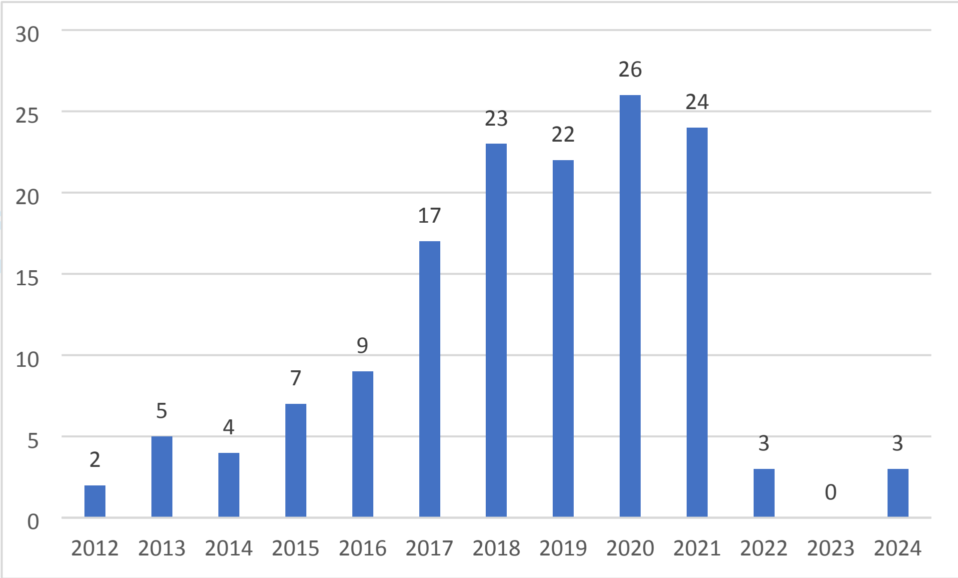

Figure 4: H&S Number of articles year-wise Source: Authors own work

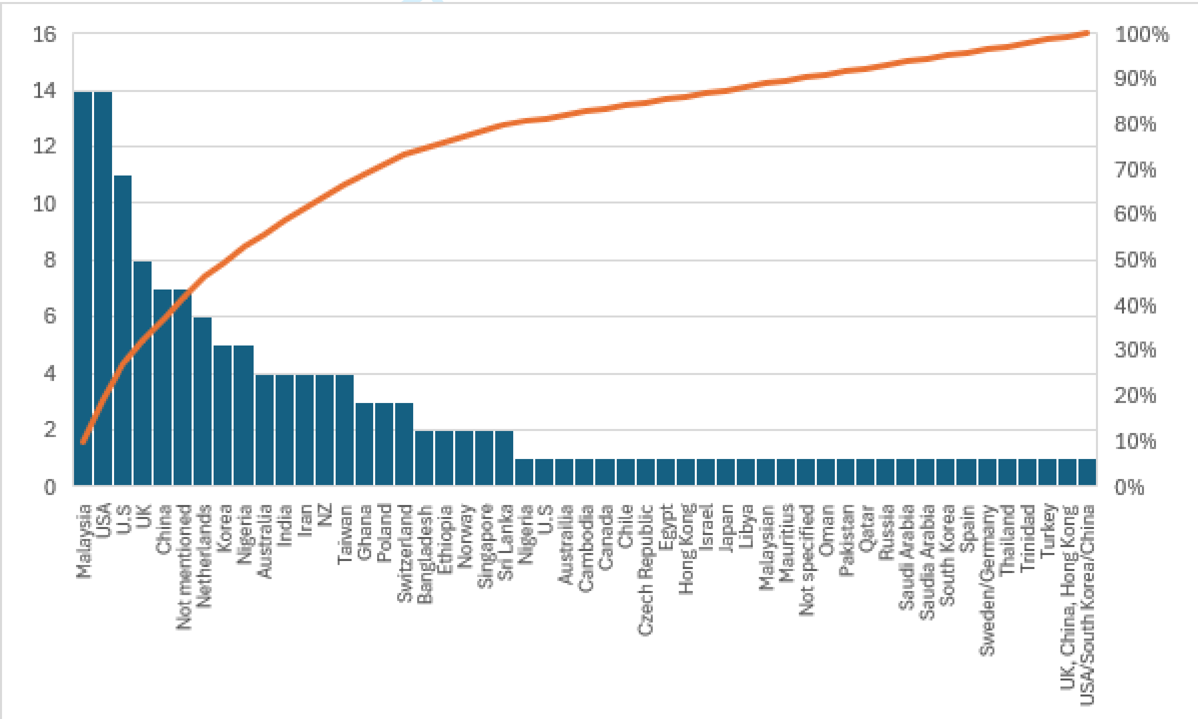

Figure 5: H&S articles published based on the countries Source: Authors own work

Figure 6 shows the method of literature selection for ST in the construction industry. Though the ST search was restricted to Post-2016 to incorporate only the latest digital technology developments, four articles from pre-2016 appeared on the list. The authors chose to keep them on the list due to their relevance and to show the historical perspective. Further search during August 2024 for ST-related papers from 2022 to 2024 did not indicate any new technologies or solutions for H&S in construction. This meant a temporary saturation. Review articles have been excluded to maintain originality. The year spread is shown in Figure 7. Visualization of SMART technology articles published based on the countries is shown in Figure 8.

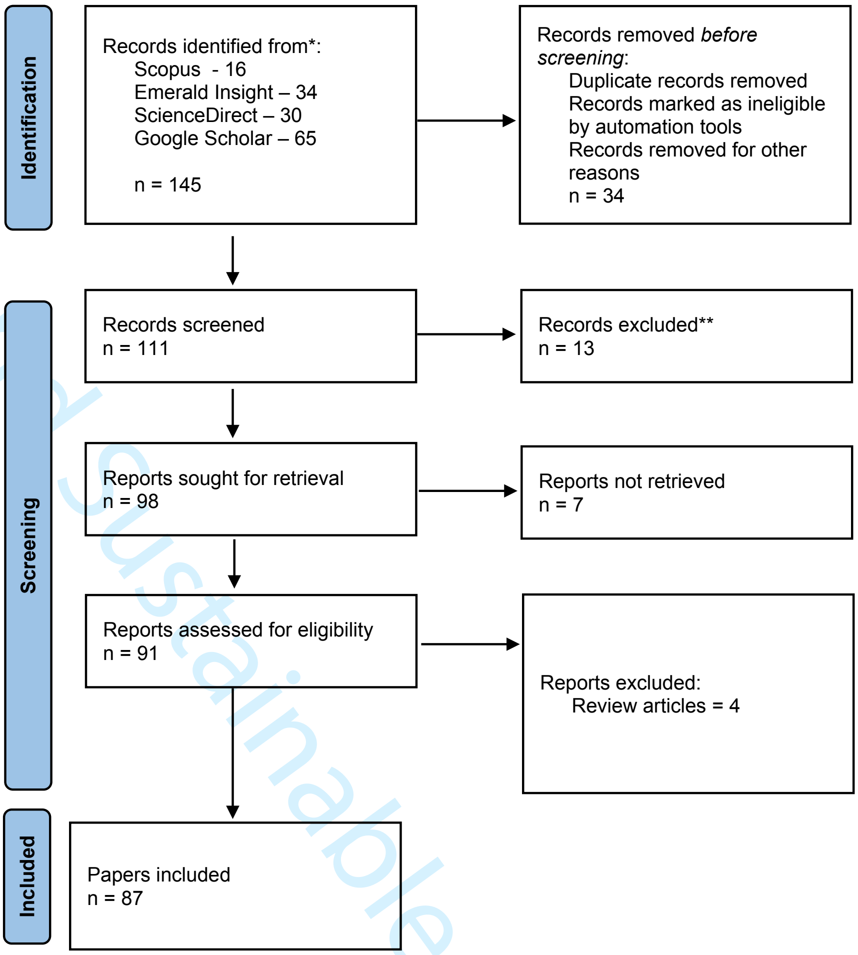

Figure 6:Identification of documents via database search for Keyword combination 2 Source: Authors own work based on Prisma guidelines (Prisma,2024)

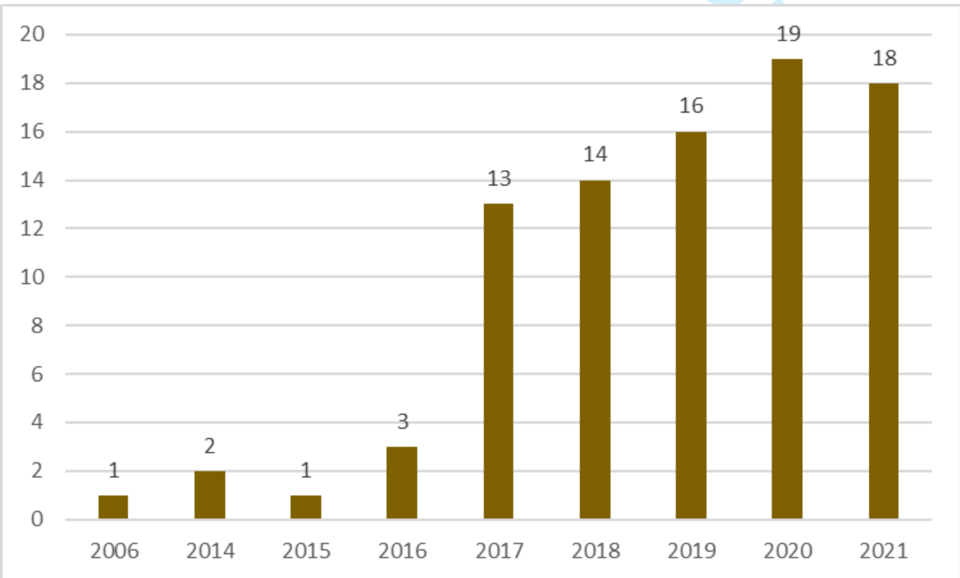

Figure 7: ST number of articles year-wise. Source: Authors own work

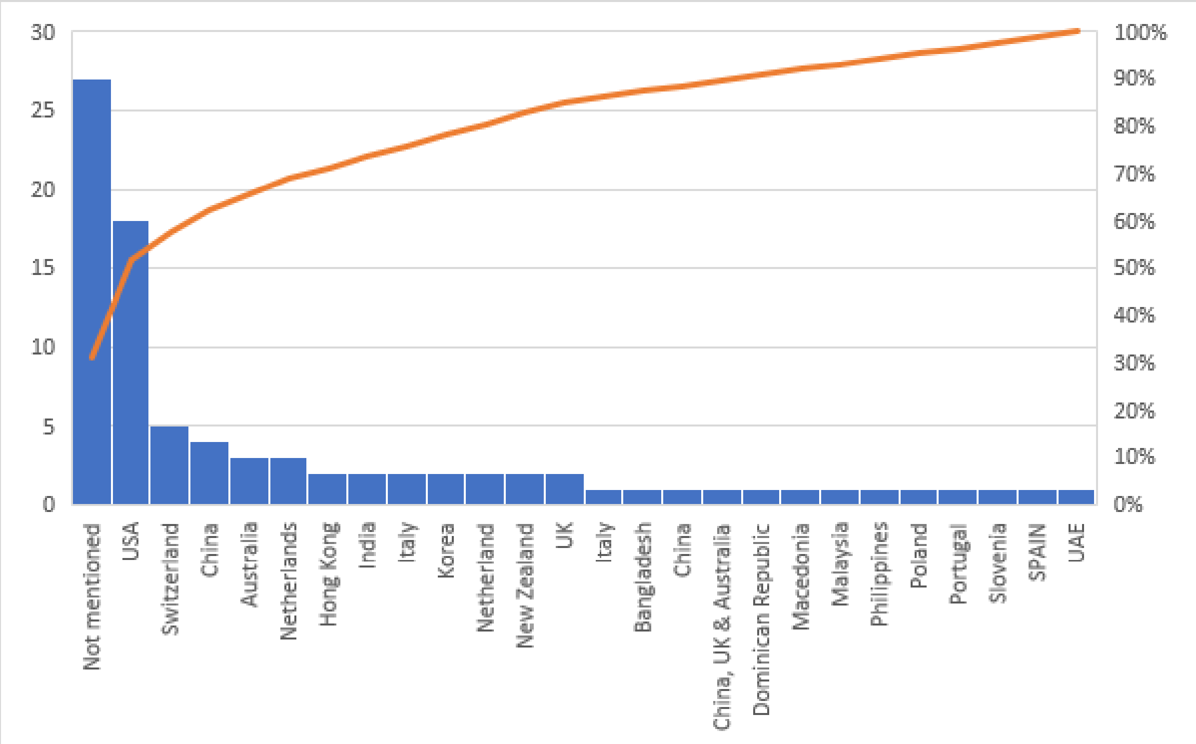

Figure 8 ST articles published based on the countries Source: Authors own work

The critical journal articles were systematically reviewed using both bibliometric and qualitative methods for analysis. A journal was maintained systematically to detail critical factors and store information from the articles. VOS viewer software, MS Word, Excel, and PowerPoint were used for analysis and results presentation. VOS viewer visualised keyword occurrence and articles published based on the countries. Each of the H&S and ST factors was further studied to identify their interlinks. The articles were read at least twice to understand the factors and their interlinks and recorded in an Excel table format in a journal. The H&S factors, ST, all the keywords, connectivity, and polarity were noted in the Excel table. The excel format was then analysed to plot the connectivity between H&S and ST factors using Vensim software. The result of this analysis is presented in a Causal loop diagram.

The Causal loop diagram illustrates the interactions between ST and H&S factors in construction, emphasizing the importance of understanding these interactions. It is crucial to note that ST, when used in isolation, cannot fully mitigate all H&S factors. However, when ST is applied in conjunction, it can significantly mitigate most of the factors that affect H&S. Therefore, understanding these interactions is beneficial and vital for the construction environment. This understanding is essential for identifying gaps in ST concerning the mitigation of H&S factors, thereby enhancing awareness of the need for integrated approaches to safety in construction.

3. SLR - Results

This review aimed to gather and analyse the past literature on the factors affecting H&S and ST in the construction industry. Table 3: Factors affecting H&S in the construction industry. A total of 145 articles revealed the 20 factors affecting H&S in construction.

Table 3: Factors affecting H&S in the construction industry

Item	Author	Origin	Year	Factors affecting H&S in the construction industry																			
				Physiological and psychological factor	Falls, Trips, and slips	Fall from heights/objects, trapped between objects	Electrocution	Machinery/Equipment Malfunction. Moving Equipment	Pollutants. Chemicals, Airborne Dust, Asbestos	Unsafe worksite	Adverse Weather Conditions	Vibrations	Violence	Legislative	Financial	Social	Cultural	Training	Communication	Disease and illness	Fire and Explosion	Over Exertion	Suicide
1	(Abas & Blismas, 2021)	Malaysia	2021		✓	✓	✓	✓	✓	✓		✓									✓		
2	(Abas et al., 2020)	Malaysia	2020	✓	✓	✓	✓	✓	✓	✓	✓												
3	(Abas et al., 2021)		2020						✓		✓							✓					
4	(Asilian-Mahabadi et al., 2020)	Iran	2020							✓													
5	(Agbolosu–Amison & Acheampong, 2021)	Ghana	2021		✓																		
6	(Agyekum et al., 2018)	Ghana	2018							✓													
7	(Ahmed, 2019)	Bangladesh	2019					✓		✓												✓	
8	(Asanka & Ranasinghe, 2015)	Sri Lanka	2015			✓					✓								✓			✓	
9	(Ashuro et al., 2021)	Ethiopia	2021		✓																		
10	(Atique et al., 2012)	Qatar	2012			✓																	
11	(Awolusi et al., 2018)	USA	2018	✓	✓	✓	✓	✓	✓	✓	✓												
12	(B. Choi et al., 2019)	Netherlands	2019	✓																			
13	(B. G. Kang et al., 2017)	USA	2017			✓	✓												✓				
14	(Bangaru et al., 2020)	Switzerland	2020	✓																			
15	(Newaz et al., 2022)	Australia	2022		✓	✓																	
16	(Betit et al., 2017)	USA	2017																				
17	(Birabakaran & Nagapan, 2021)	Malaysia	2021					✓															
18	(Brolin et al., 2021)	Sweden/Germany	2021		✓																		
19	(Brum, 2020)	Malaysia	2020	✓				✓					✓					✓					
20	(Sacks et al., 2013)	U.S	2013							✓													
21	(Vincoli, 2024)	Canada	2024			✓	✓		✓												✓	✓	
22	(Carabott, 2015)	Not mentioned	2015											✓			✓	✓					
23	(Carrillo-Castrillo et al., 2017)	Spain	2016		✓																		
24	(Chawdhry et al., 2021)	Bangladesh	2021		✓	✓	✓	✓	✓	✓		✓									✓	✓	
25	(Hwang et al., 2017)	Singapore	2017	✓	✓	✓	✓	✓	✓	✓													
26	(Chen & Demachi, 2021)	Not mentioned	2021			✓																	
27	(Nadhim et al., 2016)	Australia	2016			✓																	
28	(Peng et al., 2014)	Taiwan	2014			✓																	
29	(Zhao et al., 2016)	Taiwan	2016				✓				✓											✓	
30	(Chi et al., 2012)	Taiwan	2021				✓	✓															
31	(Cho et al., 2018)	USA	2018			✓																	
32	(Choi & Carlson, 2014)	USA	2014	✓	✓			✓		✓													
33	(Collins & Spillane, 2020)	UK	2020						✓														
34	(Durdyev et al., 2017)	Cambodia	2017		✓	✓																	
35	(Williams et al., 2019)	Nigeria	2019					✓					✓										
36	(Eskandar et al., 2019)	Not mentioned	2019	✓	✓	✓			✓		✓					✓							
37	(W. Fang et al., 2018)	China	2018			✓																	

Item	Author	Origin	Year	Factors affecting H&S in the construction industry																			
				Physiological and psychological factor	Falls, Trips, and slips	Fall from heights/objects, trapped between objects	Electrocution	Machinery/Equipment Malfunction. Moving Equipment	Pollutants. Chemicals, Airborne Dust, Asbestos	Unsafe worksite	Adverse Weather Conditions	Vibrations	Violence	Legislative	Financial	Social	Cultural	Training	Communication	Disease and illness	Fire and Explosion	Over Exertion	Suicide
38	(Murray et al., 2013)	U.S	2013		✓	✓	✓	✓	✓			✓									✓		
39	(Brauer, 2022)	U.S	2022		✓	✓	✓	✓	✓	✓		✓									✓		
40	Gelmini et al. (2020)	U.S	2020			✓																	
41	(Jaafar et al., 2018)	Malaysia	2018			✓	✓														✓	✓	
42	Ghimire and Neupane (2020)	UK	2020																	✓			
43	(Allen & Iano, 2019)	U.S	2019								✓												
44	Giri (2020)	India	2020					✓	✓	✓													
45	Glass et al. (2017)	NZ	2017						✓														
46	Goh et al. (2016)	Malaysia	2016			✓					✓												
47	Guo et al. (2019)	Not mentioned	2019	✓					✓														
48	(Abu Aisheh et al., 2022)	Malaysia	2022			✓					✓												
49	Hamid et al. (2019)	Malaysia	2019		✓																		
50	Han et al. (2013)	Malaysia	2021			✓																	
51	Hashem et al. (2013)	Libya	2013	✓	✓	✓									✓			✓					
52	(Guo et al., 2016)	USA	2016	✓	✓	✓	✓	✓	✓	✓		✓											
53	Hemler et al. (2020)	USA	2020		✓																		
54	Hoła et al. (2017)	Poland	2017							✓													
55	Hosseini et al. (2020)	Iran	2021				✓																
56	Howard (2017)	USA	2017					✓															
57	Ichikawa (2018)	Japan	2018				✓																
58	Idoga (2020)	Nigeria	2020		✓	✓	✓																
59	(Ijaola et al., 2021)	Nigeria	2021		✓	✓	✓	✓	✓	✓											✓	✓	
60	Ismail and Ghani (2012)	Malaysia	2012		✓	✓	✓	✓															
61	(Woźniak & Hoła, 2024)	Poland	2024			✓	✓																
62	Kambadur (2020)	NZ	2020		✓	✓				✓													
63	Kambadur (2020)	India	2015		✓		✓	✓		✓													
64	Kang and Ryu (2019)	Korea	2019			✓																	
65	Kantova (2017)	Czech Republic	2017										✓										
66	Kaur et al. (2021)	USA	2021																				
67	Kazar and Comu (2020)	Turkey	2020																			✓	
68	Khan et al. (2019)	Pakistan	2019		✓		✓																
69	Kim et al. (2018)	Korea	2018					✓													✓		
70	J. H. Kim et al. (2021)	Switzerland	2021		✓			✓															
71	Kim et al. (2022)	UK	2021	✓																			
72	Kurien et al. (2018)	Netherlands	2018	✓	✓			✓			✓												
73	Kuta et al. (2021)	USA	2021	✓																			
74	Lai et al. (2019)	UK, China, Hong Kong	2019																				
75	Lamm et al. (2017)	NZ	2017		✓	✓				✓													
76	(Fang et al., 2015)	UK	2015																			✓	

Item	Author	Origin	Year	Factors affecting H&S in the construction industry																			
				Physiological and psychological factor	Falls, Trips, and slips	Fall from heights/objects, trapped between objects	Electrocution	Machinery/Equipment Malfunction. Moving Equipment	Pollutants. Chemicals, Airborne Dust, Asbestos	Unsafe worksite	Adverse Weather Conditions	Vibrations	Violence	Legislative	Financial	Social	Cultural	Training	Communication	Disease and illness	Fire and Explosion	Over Exertion	Suicide
77	Lee et al. (2019)	Korea	2019					✓															
78	Lee et al. (2020)	U.S	2018			✓		✓	✓	✓		✓											
79	Leon-Kabamba et al. (2018)	Singapore	2018																	✓			
80	Lette et al. (2018)	Ethiopia	2018		✓																		
81	Li et al. (2019)	China	2019					✓															
82	Li et al. (2021)	Not mentioned	2020						✓														
83	Lingard et al. (2017)	UK	2017																	✓			
84	Liu et al. (2019)	NZ	2019	✓	✓	✓	✓	✓	✓	✓													
85	Martin et al. (2021)	Trinidad	2021																				
86	Martinez et al. (2020)	Chile	2020					✓															
87	McGuinness et al. (2019)	U.S	2019		✓	✓	✓																
88	Milner et al. (2019)	Australia	2019																				✓
89	Mizzi (2019)	UK	2019						✓														
90	Moda et al. (2019)	Nigeria	2018						✓														
91	(Kalteh et al., 2021)	Iran	2021										✓									✓	
92	Mohammadi et al. (2018a)	Iran	2018								✓											✓	
93	Mohd Amir Shazwan and Ee (2018)	Malaysia	2018																				
94	Morrissey et al. (2021)	Not mentioned	2021								✓									✓			
95	Moshashaei et al. (2017)	Norway	2017					✓													✓		
96	Mostly (2022)	Saudia Arabia	2019																				
97	Nadhin et al. (2016)	Switzerland	2016		✓	✓					✓												
98	Namian et al. (2021)	U.S	2021			✓		✓															
99	Nath et al. (2017)	Netherlands	2017	✓					✓														
100	(Zhang et al., 2015)	U.S	2015		✓			✓		✓												✓	
101	Osei-Asibey et al. (2021)	Ghana	2021								✓								✓			✓	
102	Panuwatwanich et al. (2020)	Thailand	2020			✓																	
103	Park et al. (2020)	South Korea	2020				✓				✓											✓	
104	Patel et al. (2021)	U.S	2018					✓															
105	Pedley (2021)	Not mentioned	2021		✓																		
106	(Tadesse & Israel, 2016)	Israel	2016			✓																	
107	Rafindadi et al. (2022)	Malaysian	2020			✓		✓															
108	Rameezdeen and Elmualim (2017)	Australia	2017																			✓	
109	Robert et al. (2018)	U.S	2018					✓					✓										
110	S. D. Choi et al. (2019)	USA/South Korea/China	2019		✓	✓																	
111	(Ramkalawon Veerapen Chetty et al., 2024)	Mauritius	2024		✓	✓	✓	✓	✓	✓		✓									✓	✓	
112	SAMUEL (2019)	Malaysia	2017		✓		✓																
113	Sanni-Anibire et al. (2020)	Saudi Arabia	2019		✓																		

Item	Author	Origin	Year	Factors affecting H&S in the construction industry																			
				Physiological and psychological factor	Falls, Trips, and slips	Fall from heights/objects, trapped between objects	Electrocution	Machinery/Equipment Malfunction. Moving Equipment	Pollutants. Chemicals, Airborne Dust, Asbestos	Unsafe worksite	Adverse Weather Conditions	Vibrations	Violence	Legislative	Financial	Social	Cultural	Training	Communication	Disease and illness	Fire and Explosion	Over Exertion	Suicide
114	(Sacks et al., 2013)	UK	2013								✓											✓	
115	Sazonova et al. (2018)	Russia	2018						✓														
116	Sehsah et al. (2020)	Egypt	2020			✓		✓															
117	Shafique and Rafiq (2019)	Hong Kong	2019		✓																		
118	Shiau et al. (2020)	China	2020				✓																
119	Smith et al. (2014)	USA	2014		✓																		
120	Szóstak et al. (2021)	Poland	2021			✓																	
121	Tamburrini et al. (2020)	India	2020						✓														
122	(Thomas & Sudhakumar, 2014)	India	2014						✓														
123	(Tran et al., 2021)	Korea	2020							✓											✓		
124	Tunji-Olayeni et al. (2018)	Nigeria	2018		✓	✓			✓				✓										
125	Umar and Egbu (2018)	Oman	2018																			✓	
126	Valero et al. (2017)	Netherlands	2020	✓																			
127	Vitharana et al. (2015)	Sri Lanka	2015	✓	✓	✓	✓	✓	✓	✓		✓											
128	Walters and Quinlan (2019)	UK	2018						✓														
129	Williams et al. (2018)	Malaysia	2018		✓				✓														
130	Williams et al. (2019)	Nigeria	2019		✓																		
131	Winge et al. (2019)	Norway	2018			✓	✓	✓															
132	Xiao et al. (2016)	China	2016										✓										
133	Xiong et al. (2019)	China	2019		✓	✓		✓					✓								✓	✓	
134	Xu and Xu (2021)	China	2021			✓																	
135	Y. Kang et al. (2017)	USA	2017		✓	✓	✓	✓															
136	Yan et al. (2018)	Netherlands	2018	✓																			
137	Yang et al. (2016)	Netherlands	2016		✓																		
138	Yang et al. (2017)	U.S	2017		✓	✓		✓														✓	
139	Yang et al. (2020)	USA	2020																		✓		
140	Yang et al. (2021)	China	2021										✓										
141	Yap and Lee (2020)	Malaysia	2020	✓	✓	✓	✓	✓	✓	✓													
142	Yi (2020)	Korea	2020																		✓		
143	Yoon et al. (2013)	Taiwan	2013	✓				✓	✓		✓								✓				
144	Zhao et al. (2015)	U.S	2015	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										
145	Zuo et al. (2017)	Australia	2017						✓														
	Totals			**22**	**50**	**54**	**32**	**43**	**34**	**26**	**18**	**9**	**10**	**1**	**1**	**1**	**1**	**4**	**4**	**4**	**14**	**20**	**1**

Source: Authors own work

All the H&S factors that appeared in keywords are selected and visualized in Figure 9. Figure 10 shows the Pareto diagram of factors affecting H&S in construction.

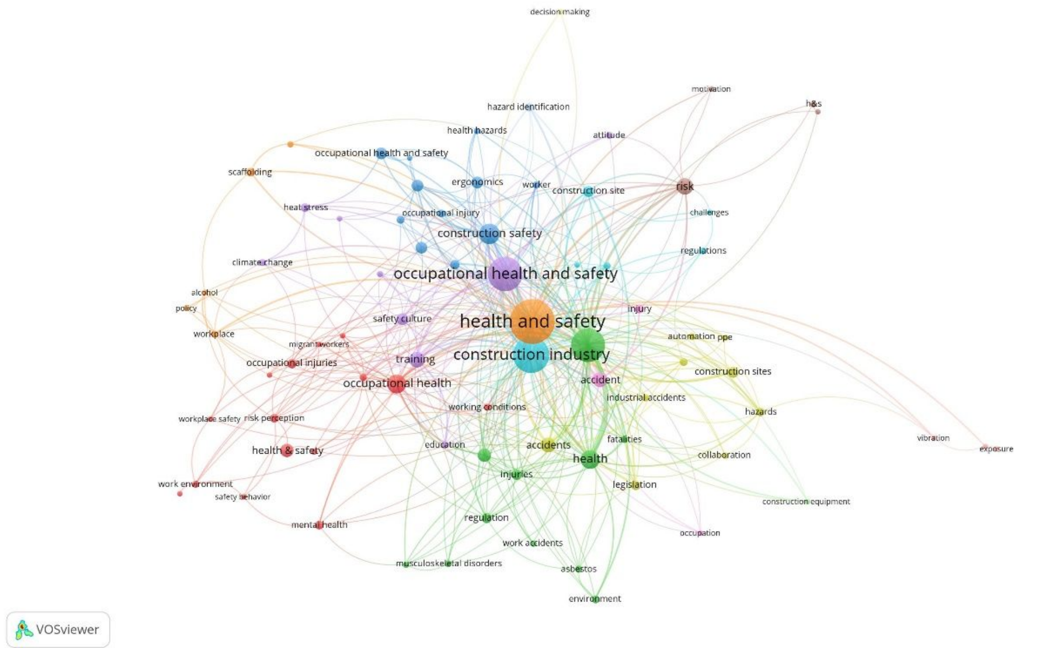

Figure 9:Visualization of keywords occurrence of H&S factors in construction   Source: Authors own work using Vos viewer

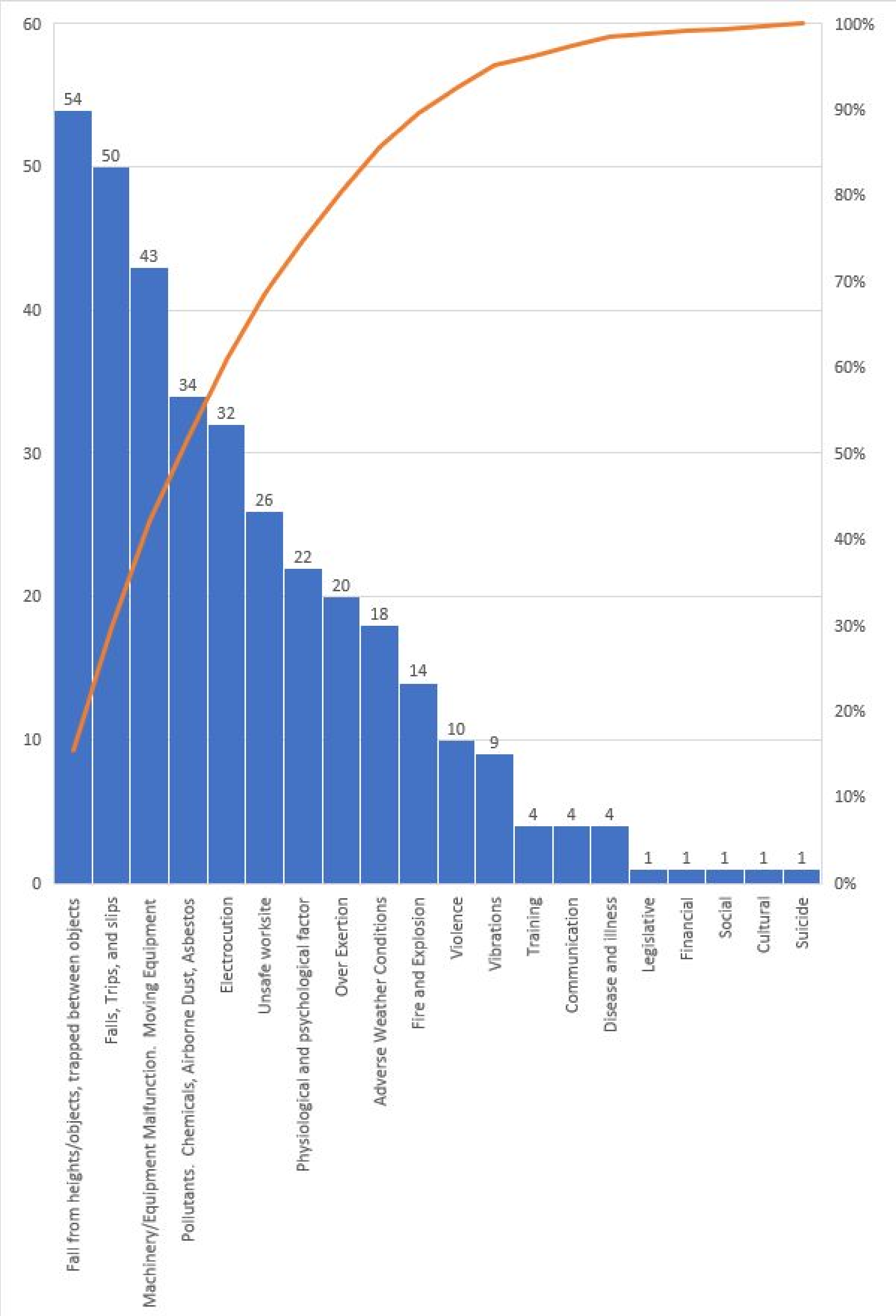

Figure 10 Pareto chart of factors affecting H&S in Construction Source: Authors own work

Table 4 classified the literature on utilizing SMART technology to mitigate H&S hazards. Figure 11 shows the visualization of the occurrence of keywords in SMART technology concerning H&S in construction. Figure 12 shows the Pareto chart of SMART technology concerning H&S in construction.

Table 4: ST in the Construction Industry

No.	Author	Origin	ST in Construction								
			Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch	Mobile Apps	Building Information Modelling, Virtual Reality, and Augmented Reality	Geofence	Drones/ Unmanned Aerial Vehicles	Wearable Technology/Mobile Sensors	Communication and Video Technology	Robot	Geographic Information Systems
1	Abainza et al. (2020)	Philippines	✓	✓				✓	✓		
2	Adjiski et al. (2019)	Macedonia	✓								
3	Ahmed (2019)	Bangladesh		✓		✓			✓		
4	Ahn et al. (2019)	United States	✓								
5	Akinosho et al. (2020)	Netherland			✓		✓			✓	
6	Alizadehsalehi et al. (2020)				✓		✓				
7	Ammad et al. (2021)	Malaysia	✓	✓				✓	✓		
8	Anast et al. (2021)					✓					
9	Antwi-Afari et al. (2019)	Hong Kong	✓								
10	Ashour et al. (2016)	UAE	✓				✓			✓	
11	Ashtekar et al. (2019)		✓								
12	Awolusi et al. (2018)	USA	✓	✓							
13	Azzazy et al. (2021)	NZ	✓								
14	B. Hwang and S. H. Lee (2017)	Netherlands	✓								
15	Baek and Choi (2020)	Korea		✓							
16	Banerjee and Nayak (2021)	Not mentioned		✓	✓						
17	Bangaru et al. (2020)	USA									
18	Barata and da Cunha (2019)	Portugal	✓								
19	Bolshakova et al. (2018)				✓						
20	Callejas Sandoval and Kwon (2019)	USA	✓								
21	Camero-Jurado et al. (2020)	Switzerland	✓								

No.	Author	Origin	ST in Construction								
			Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch	Mobile Apps	Building Information Modelling, Virtual Reality, and Augmented Reality	Geofence	Drones/ Unmanned Aerial Vehicles	Wearable Technology/Mobile Sensors	Communication and Video Technology	Robot	Geographic Information Systems
22	Chan et al. (2020)		✓								
23	Cheng et al. (2019)								✓		
24	Choi et al. (2017)	USA	✓	✓				✓	✓		
25	Ciampa et al. (2018)	Italy					✓				
26	Dogbe et al. (2020)	USA	✓	✓							
27	Edirisinghe (2019)	Australia			✓						
28	Fargnoli and Lombardi (2020)		✓		✓						
29	Ganah and John (2015)	UK		✓	✓				✓		
30	Getuli et al. (2018)	Italy			✓						
31	Gheisari and Esmaeili (2016)	U.S	✓								
32	Guo and Li (2021)	China	✓	✓							
33	Haq (2020)	Australia	✓			✓					
34	Haupt et al. (2019)	Not mentioned	✓	✓	✓					✓	
35	Howard (2017)						✓				
36	Jayasree and Kumari (2020)	India	✓								
37	Jiang et al. (2021)	Netherland					✓			✓	
38	Jiang et al. (2021)				✓						
39	Johansson et al. (2019)		✓								
40	Kang and Ryu (2019)	USA								✓	
41	Kim et al. (2018)	Switzerlan d	✓								
42	Lee et al. (2020)								✓		
43	Li (2017)	Hong Kong									✓
44	Liu et al. (2019)	NZ		✓					✓		
45	Liu et al. (2021)	USA								✓	
46	Luo et al. (2020)	China	✓	✓							
47	Manzoor et al. (2021)				✓						
48	Marefat et al. (2018)	USA	✓		✓						
49	Márquez-Sánchez et al. (2021)	Switzerlan d	✓								

No.	Author	Origin	ST in Construction								
			Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch	Mobile Apps	Building Information Modelling, Virtual Reality, and Augmented Reality	Geofence	Drones/ Unmanned Aerial Vehicles	Wearable Technology/Mobile Sensors	Communication and Video Technology	Robot	Geographic Information Systems
50	Martin and Voix (2017)		✓								
51	Mehata et al. (2019)	India	✓								
52	Mordue and Finch (2019)				✓						
53	(Motawa & Kardakou, 2018)				✓		✓				
54	Nath et al. (2017)	USA	✓	✓				✓	✓		
55	Niu et al. (2016)	USA	✓	✓							
56	Nnaji et al. (2021)	Switzerland	✓								
57	Park et al. (2017)	USA	✓	✓							
58	Parn et al. (2019)	UK	✓								
59	(Podgorski et al., 2017)	Poland	✓								
60	Q. Fang et al. (2018)		✓								
61	Rajendran et al. (2020)	Netherlands	✓								
62	Rey-Mercvhan et al. (2021)	Switzerland	✓								
63	(Maali et al., 2024)	USA	✓	✓	✓	✓		✓	✓		
64	Riaz et al. (2014)	Australia			✓						
65	Robert et al. (2016)	USA	✓								
66	Roofigari-Esfahan et al. (2021)		✓								
67	S. Hwang and S. Lee (2017)	United States	✓								
68	Sanchez et al. (2021)	SPAIN	✓			✓					
69	Shafiq et al. (2021)		✓		✓						
70	Shahrour et al. (2021)	Netherlands	✓		✓						✓
71	Silverio-Fernandez et al. (2019)	Dominican Republic									
72	Srinivasan and Chander (2021)		✓								
73	Stefanic and Stankovski (2019)	Slovenia	✓		✓						
74	Svertoka et al. (2021)		✓								

No.	Author	Origin	ST in Construction								
			Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch	Mobile Apps	Building Information Modelling, Virtual Reality, and Augmented Reality	Geofence	Drones/ Unmanned Aerial Vehicles	Wearable Technology/Mobile Sensors	Communication and Video Technology	Robot	Geographic Information Systems
75	Tokunova and Rajczyk (2020)				✓						
76	W. Fang et al. (2018)	China, UK & Australia									
77	Wang et al. (2020)	Korea	✓	✓				✓	✓		
78	(Getuli et al., 2020)	Italy			✓						
79	Y. Kim et al. (2021)		✓								
80	Yang et al. (2020)	China	✓	✓							
81	Yiu et al. (2018)					✓					
82	Yu et al. (2019)		✓								
83	Zhang et al. (2017)	China	✓		✓						
84	Zhao and Lucas (2015)	United States			✓	✓					
85	Zhou et al. (2018)	China	✓	✓	✓						
86	Zimbelman et al. (2017)	US				✓		✓	✓		
87	Zulu and Muleya (2018)				✓		✓				
	Totals		**54**	**20**	**25**	**8**	**8**	**7**	**12**	**6**	**2**

Source: Authors own work

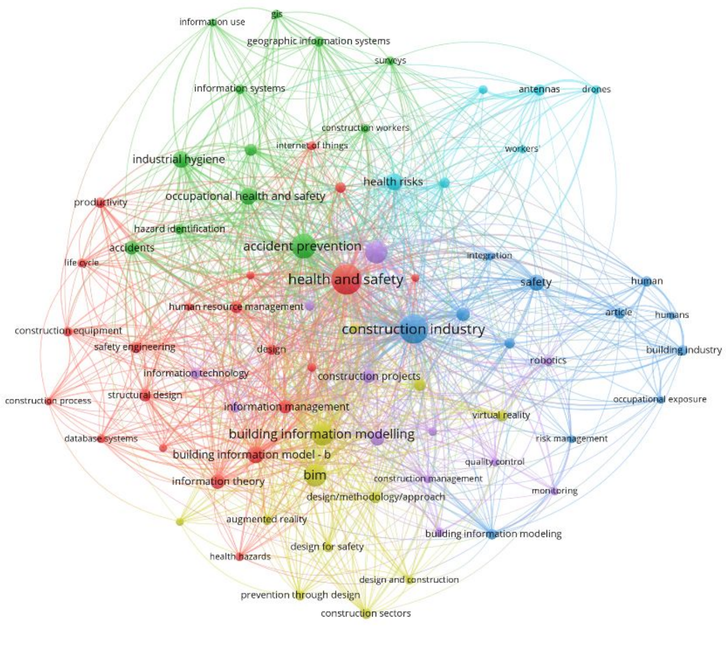

Figure 11: Visualization of keywords occurrence of H&S factors in construction Source: Authors own work using VOS viewer

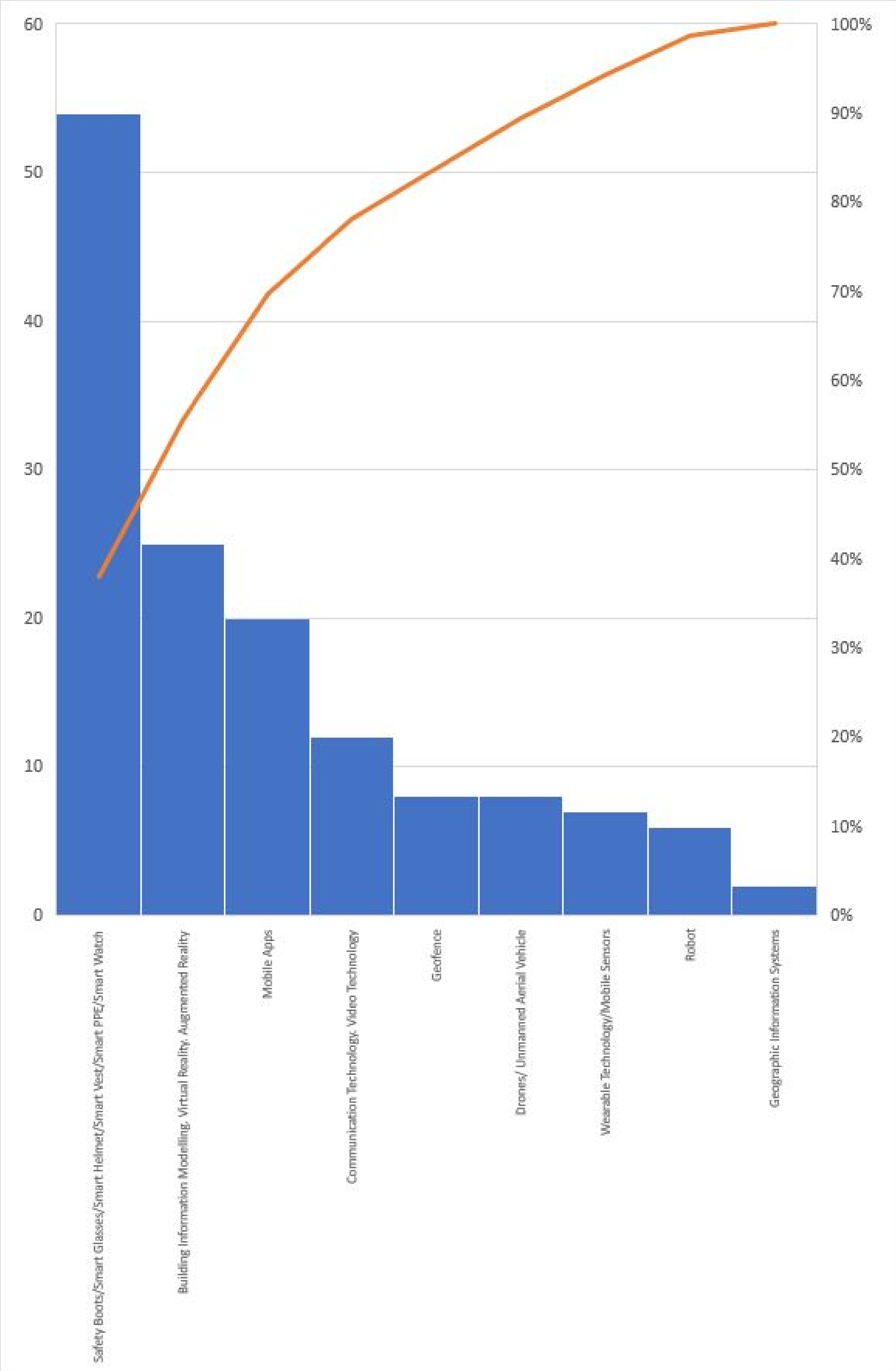

Figure 12: Pareto chart of SMART technology concerning H&S in construction Source: Authors own work

4. Discussion

A country's economic and social well-being depends critically on H&S. Given that the construction sector touches many lives, it is crucial to talk about how technological advancements have enhanced H&S in the industry and, even better, how they have impacted a wide range of stakeholders. Modest construction projects are prone to overlooking H&S hazards on the worksite. FTS, cuts, burns, scalds, electrocution, and unintentional poisoning are among the several accidents. By following the Extremely Important H&S Rulebook, which includes assessing potential difficulties on compact work sites, employees may avoid regular problems and safeguard the H&S of everybody involved. The broad SLR of more than 232 academic journals and additional reports, legal requirements, and conclusions served as the basis for this discussion. The SLR highlighted health-related concerns or factors that affect construction workers' safety and SMART technology that can be used to reduce risk and enhance workplace safety.

Idoga (2020) stated that the significant factors of construction accidents are widely recognised globally, often called the “Focus or Fatal Four”. It includes falls, falling objects, being trapped between objects and electrocution. This SLR had identified “Focus or Fatal Five”, which combined form 60% of factors identified by various listed authors (refer to Figure 10 and Table 3); it includes:

1. FFH (objects) and trapped between objects
2. FTS
3. Machinery/Equipment Malfunctionand Moving Equipment
4. Pollutants: Chemicals, Airborne Dust, Asbestos
5. Electrocution

Pollutants: Chemicals, Airborne Dust, and Asbestos appeared fourth and above electrocution in the list, which Idoga (2020) had not listed in his “Fatal Four”. The top was FFH, where a falling or projected object struck the worker. The object could be part of the work or equipment, causing it to fall or fly (Idoga, 2020). Similarly, being trapped between objects is when the worker is between a stationary and one in motion (Idoga, 2020). This happens when a building might collapse or be squashed beneath something that has fallen, catching a body part in a machine. Falls often happen from heights on buildings and on industrial and construction sites (Idoga, 2020). It could occur due to faulty scaffolding, an unstable work surface or structural element, unsafe ladders, human error, or the lack of fall protection equipment (Idoga, 2020). ST has been considered to reduce the occurrence of the “Fatal five” in construction and enhance H&S.

Literature research has discovered that modern innovative technologies have integrated well into the construction H&S sectors. Yap, Lee, & Wang (2023) findings revealed that the most effective Smart technologies for construction safety management were wearable technologies, building information modelling, and robotics and automation that are applied to improve hazard identification and enhance safety planning, inspection, monitoring, supervision, and awareness. Six out of 87 Articles on ST in Construction Industries (refer to Table 4) have discussed robots. Robotics are being adopted for sustainable construction (Oke et al., 2024). However, barriers to implementation, such as the fragmented nature of the construction process, resistance by workers and unions, hesitation to adopt innovation, lack of capacity and expertise and lack of support from top-level managers, prevent widespread use (Oke et al., 2024). The barrier clusters include industry, human, economic and technical-related (Oke et al., 2024).

Table 4 shows that the highest factor of the ST is Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch, which 54 Articles out of 87 have considered. Nnaji et al. (2021) found that "These Smart wearables are useful on construction sites for detecting near-miss falls or reducing fall-related injuries, identifying unsafe posture in workers and potential work-related ergonomic risks, monitoring workers' fatigue and workload stress, and other applications." SMART Wearables are available in a wide range of sizes and shapes. Some businesses are quick to jump on board concerning ST, but in the construction industry, the outcome is perceived as slow (Wakefield & Kassem, 2020). For various reasons, many people are hesitant to use wearable technology.

According to Table 4, BIM and mobile apps were in second and third positions, respectively. The BIM technology was discovered to be helpful for danger perception, risk assessment, and spotting safety-related design errors. Additionally, BIM may "integrate data from multiple capture technologies like photogrammetry, GPS, GIS, RFID, augmented reality, virtual reality, laser scanning, and rapid response (QR) coding to provide a variety of detailed data and information about a project, particularly for improving the construction site safety”. Furthermore, BIM (Building Information Modelling) is a software that allows for 3D modelling and better collaboration and communication between everyone involved in the project through easy real-time access to updated information. The same can be said for virtual reality and augmented reality modelling, which has been highly praised for allowing workers to interact, look around, and be transported in a virtual environment for their H&S training and learning (Zhao & Lucas, 2015). Besides digital modelling options, drones and geofencing also act as preventative measures for workers, as they can scan and survey building sites and alert them of equipment and machinery locations or possible collisions to guarantee safety and contribute to a safer working environment. Combining various STs used in the construction site may yield better results. The literature review also revealed that Unsafe worksites and practices could be reduced with the help of BIM, Unmanned aerial vehicles (UAVs) and mobile applications.

UAVs have the added benefit of enabling businesses to gather data in circumstances where doing so securely in the past would have been prohibitively challenging or time-consuming, such as conducting surveys in hot climes or inspecting large structures or power lines. Essential advantages include extreme mobility and the ability to take high-quality photographs using drones for less money than with traditional helicopter-assisted photography (Stefanic & Stankovski, 2019). The information gathered by drones can be transformed into volumetric measurements, topographic maps, and 3D structural models to assist architects and builders in planning their projects. As most workers would have access to a mobile device, such as a mobile phone, other technological advances developed to assist with H&S are mobile applications like iAuditor or Safety Meeting, which are safety-focused.

ST may be a source of hazard, too. For example, an uncrewed aerial vehicle (drone) can pose a safety risk. Drones flying away is a common issue. This happens when the wireless Wi-Fi is out of range for the drone, and there is no connection between the drone controller and the aircraft. When this happens, the drone will fly until the battery is depleted and will then make an emergency landing at that position. These landings can be on anywhere. Geofencing is an option to prevent a drone from a flyaway. When geofencing has been set up around the area, the drone will only fly in that area and at a specified height. Another example is SMART PPE. Construction team members must know sufficiently about the PPE's capabilities, how to wear it appropriately, and maintenance advice (Sharma, 2019). The fit should be appropriate for the workers, who must use personal protective equipment. (Sharma, 2019).

Contrary to common assumption, personal protection equipment may raise thermal strain in potentially dangerous workplace conditions, leading to tiredness and decreased productivity; there are many elements to consider when creating protective gear that would provide users with enough protection and comfort (Khlaponin et al., 2020). These include fabric type, the design and care given to textiles, and the construction and fit of clothing (Khlaponin et al., 2020). However, it is advisable to consult the manufacturer's instructions or handbook before beginning a task (Stefanic & Stankovski, 2019). Due to these risks, vision-based non-wearable technologies in H&S are gaining significance as they pose fewer H&S risks created by wearable devices (Purushothaman & Gedara, 2023). Similar technologies, such as AR and VR, are primarily applied to on-site real-time information retrieval and health and safety measures in the construction sector (Oke & Arowoiya, 2022). Seyman Guray and Kismet (2023) state that VR-AR technologies mostly attract the interest of researchers from architectural design studies but lack in construction management. In contrast, Zoleykani et al. (2024) state that virtual reality or extended reality (XR) technologies are the most used XR tools, with most of their applications dedicated to safety training and risk management. Khorrami Shad et al.'s (2024) study results indicate that AR integration with construction effectively mitigates safety concerns.

The following sub-sections discuss the links between "Focus or Fatal Five" and ST.

4.1. Fall from heights

Table 3 reveals that FFH (objects) and trapped between objects is the most dangerous hazard, accounting for 15.47% of the list of collected literature. Fifty-four authors listed it as a critical factor. This substantiates the findings of (Zhang et al., 2015) and (Kim et al., 2020), who provided data on the US and the UK. NZ also had a similar FFH. Figure 2 shows the data on incidents due to FFH between Nov 2019 and Oct 2020 in NZ. Worldwide, these mishaps are categorised under the critical H&S risk. For instance, falls are the second most common reason for accidental mishaps, according to WHO reports from April 2021. Worldwide, 684000 people die from fall-related accidents yearly (Arquillos et al., 2012).

The Fall from Heights factor is one of the most dangerous hazards on site that harms all the stakeholders; at least eleven authors recorded that most construction fatalities occur when people fall from heights. This risk can be minimized by inspecting the site conditions before construction operations using UAV in conjunction with BIM. When properly used, these STs can minimize and will be able to assist in identifying the risk of Falling objects in advance. While wearing hard helmets, employees' heads are shielded from falling objects, projecting objects, electrical contact, UV radiation, weather conditions, and severe temperatures. Workers must wear hard helmets that adhere to AS/NZS 1801:1997 if something is possibly falling from the ceiling (or a comparable standard). Hard helmets are becoming increasingly common on building sites, for example, in NZ, especially where a path of unevenly stained stones or an oily or wet floor could be a potentially hazardous work environment (Ranasinghe et al., 2023).

Srujana (2019) provided a list of safety gear that should be used on the job site. For workers in the construction industry, headgear is worn to protect the head from harm from falling objects; this protective gear is a requirement in the construction industry. Protection for the face and eyes is also a requirement for construction. When invisible objects or dirt flecks get in the eyes, the protective equipment should shield the face, especially the eyes (Srujana, 2019). Additionally, hearing protection is required to protect the ears from loud noises. The use of these hearing aids guards against ear damage.

4.2. Falls, Trips, and slips

In Table 3, FTS are ranked second, with 50 authors listing them as critical factors. Surface contaminants such as water and oil are related to the physical work environment and are common causes of FTS. According to Smith (2024), construction sites are highly susceptible to incidents involving FTS. In 2021, nearly 20% of workplace fatalities occurred in the construction industry, with over a third of these deaths attributed to FTS. The majority of these fatalities were due to people falling from a height in work spots, constituting 46.2% of all fatal FTS accidents that year. Spot-r recognises when a worker trips and falls so that managers are immediately alerted, which is yet to be widely used. A path of unevenly stained stones or an oily or wet floor could be a potentially hazardous work environment and cause FTS (Ranasinghe et al., 2023). With worker push-button warnings and spot-automated fall detection, staff can react to accident occurrences much more quickly, which helps to save critical reaction time (Wakefield & Kassem, 2020). The SMART wearables can also provide data on the area and time of incidents (Wakefield & Kassem, 2020). Knowing when these incidences occur is highly beneficial for investigating accidents and enhancing the general safety culture on the building site (Xu et al., 2022). Awolusi et al. (2018) point out that wearables perform different functions like collecting, storing and receiving information about the workers' biometric signs, location, possible nearby hazards and further work site data. For example, a spot-r or sensor device can be attached to the worker's belt, and it alerts management if they are in a high-risk area or detects falls before they happen.

4.3. Machinery/Equipment Malfunctionand Moving Equipment

Hazards related to Machinery/ Equipment malfunction are the third highest H&S factor, according to Table 3. Smith (2024) examined the fact that accidents occurred despite implementing machine safety measures. After utilising the machine safeguards, they claim that accidents were not avoided since the precautions could not stop all machine actions. According to Lingard, Cooke and Gharaie (2013), backhoes and rollovers were the leading causes of work-related fatalities in the construction industry, and worker contact with heavy machinery and equipment was deemed the scariest incident. Each year, average machine entanglements cause roughly 34,000 industrial injuries (CMA, 2022). Workers in the manufacturing sector sustained about 12 % of the injuries. Most fatalities at work due to machines also come from this sector (about 41 %). Most of the remaining machine-related occupational injuries and fatalities are caused by agricultural, mining, construction, and waste management businesses (CMA, 2022).

Machine Accidents are the most common fatality factor due to the heavy machinery used on site. Machine accidents usually occur when there is a lack of concentration on the operator's side. Machine accidents have a negative impact on the H&S team as well as the operator. People working in the construction industry must wear vibrant colours to indicate the presence of a person at a distance. Reflective clothing is necessary; this clothing is helpful at night or when visibility is reduced. (Srujana, 2019). Workers in the construction industry are more likely to be seen by motorists when they are dressed in high-visibility gear (Edirisinghe, 2019), such as SMART vests. These accidents can be minimized by using SMART sensors for noise monitoring. The audio-based event detection also assists in identifying where this huge machinery works. The SMART cap and SMART watch will positively impact this risk. These SMART wearable technologies will detect if the operator is tired and the operator's well-being whilst operating the machine. SMART vests can aid in emitting an acoustic alarm or sending a signal to the front or rear machines, automatically slowing it down to a manageable speed. Further, Using

SMART vests can provide additional benefits and data. For example, Hexoskin SMART Garments features textile sensors to track activity and heart rate monitoring for accurate, real-time monitoring. Customers can access, report, and analyse the data collected from their devices using Hexoskin's Connected Health Platform (Riaz et al., 2014)

4.4. Pollutants

Pollutants or exposure to harmful substances and the environment are the next highest factor in Table 3, with 34 authors referring in their studies. Building site pollution includes asbestos, silica dust, lead paint, solvents, timber preservative chemicals, sediment and run-off. The dangers of exposure to airborne and other contaminants may not be immediately apparent. The leading cause of work-related mortality in NZ now is past asbestos exposure, which is thought to be responsible for 220 deaths annually. Construction sites could present a risk from silica dust (Level.org.nz, 2021). Pollution is present primarily in construction due to chemicals, which can cause Skin diseases. SMART clothing, SMART cap, SMART watches geofencing, and wireless wi-fi could assist the H&S team. These technologies will immediately identify if the worker is in a contaminated area. When exposed, the SMART clothing, a SMART cap and a SMART watch will report the body temperature, the brain condition, and the worker's well-being. These technologies combined can provide the H&S team with an idea of the employee's condition. The Slip and trip factor harms all the stakeholders as this is one of the most common hazards on a construction site, with the SMART helmet, SMART gloves, SMART boots, spot-r clips, the building information modelling and the UAV (Márquez-Sánchez et al., 2021). This risk can be recorded and analysed to minimise the hazard's impact. Workers who wear foot protection are less likely to trip or slip. Employees' use of non-work shoes must be avoided since it increases the risk to their safety (Srujana, 2019). This factor might even be removed with the assistance of Building Information Modelling technology. Eight of the authors mentioned that these STs would positively impact this risk.

4.5. Electrocution

One of three ways can result in electrocution: Ionization, known as arc flash, occurs when electricity is transmitted through two conducting metals. Arc blast: During an arc flash, a fault current causes some pressure wave components (Idoga, 2020). This quick increase in the mixture of vaporisation and air exacerbated by conducting materials causes the pressure to weave components known as an arc blast (Idoga, 2020). Electrical shock has caused many construction-related injuries and even fatalities (Idoga, 2020). Employees have a high workload, from working around the clock to completing projects on time, fulfilling corporate goals, and supporting the company's general mission (Ranasinghe et al., 2023). This necessitates speeding up work and practising shortcuts, leading to H&S issues (Ranasinghe et al., 2023). Electrocutions occur when construction companies use undeveloped and under-protected electrical sources on site. These temporary electrical installations need to be checked daily and serviced regularly. Safety gloves are essential tools every construction worker should have (Sharma, 2019); specific gloves must be utilized when working with electricity. Though SMART technology cannot prevent electrocution, SMART shirts, SMART clothing, and SMART watches will assist the H&S team with determining the workers' condition after electrocution. SMART shirts will monitor heart rate, SMART clothing will control body temperature, and the SMART watch will report on the worker's well-being. However, SMART wearable technology that can still prevent electrocution is yet to be commercialized. To prevent electrocution, SMART PPE (Personal Protection Equipment) wearables catered specifically for hazardous electrical sites can protect workers from electrocution or electric shock (Srujana, 2019). Aside from electrocution, SMART PPE can also be used when working with toxic substances (Sharma, 2019). Specific body sensors have also been utilised to detect and mitigate bodily injuries due to the labour intensity of a construction worker.

4.6. ST interactions

54 out of 87 authors advocated Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch use in Construction H&S. 20 authors connected Mobile Apps to Construction H&S. Building Information Modelling, Virtual Reality and Augmented Reality were connected to Construction H&S by 25 authors. Eight authors connected Geofence, Drones/ Unmanned Aerial Vehicles. Similarly, Wearable Technology/Mobile Sensors were connected by eight. Eight authors focused on communication and Video Technology, while 6 discussed the Robot's part in the Construction of H&S. 2 authors linked Geographic Information Systems to the Construction of H&S.The SLR revealed that the ST used as a standalone is less effective and often works in conjunction with others. SL analysis revealed the ST currently used, its interrelations and its connectivity to H&S (refer to Figure 13).

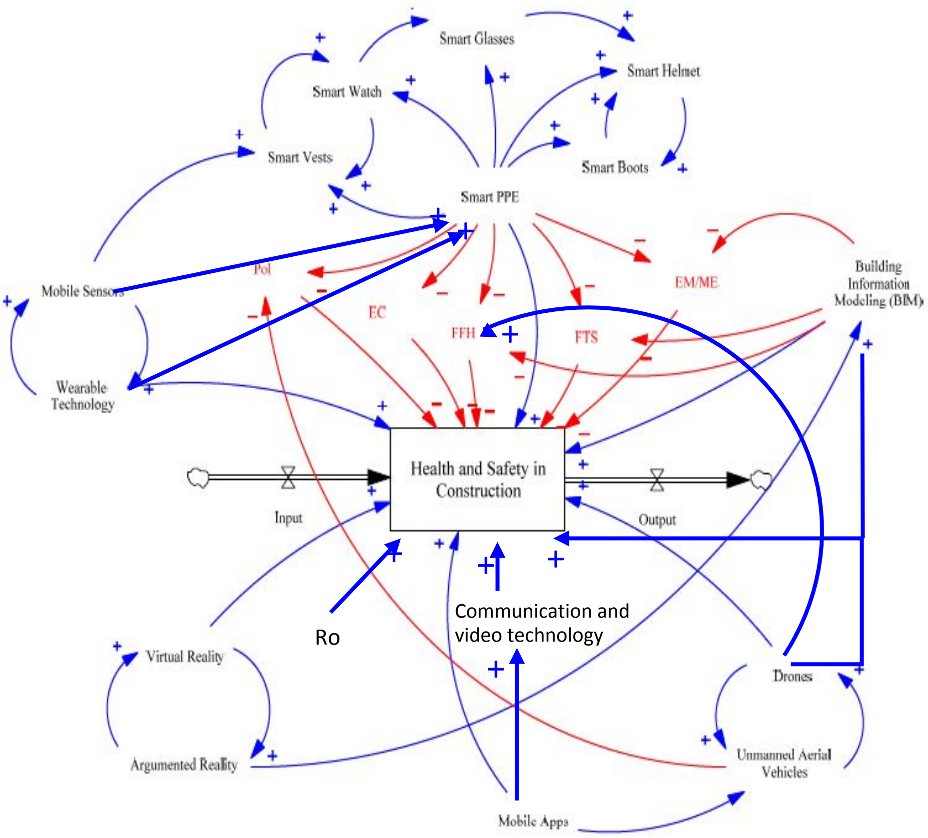

Figure 13 Interactions of factors affecting H&S and ST Source: Authors own work using Vensim software

Safety Boots, SMART Glasses, SMART Helmet, SMART Vest, SMART PPE, and SMART Watch were interconnected and connected to SMART PPE (Abainza et al., 2020; Dogbe et al.,2020). Many authors state they are used in conjunction (Y. Kim et al.,2021), Yang et al.,2020). SMART PPE is connected to mobile apps, which play a crucial role in integrating and managing data from various safety technologies (Guo & Li,2021), and mobile apps are connected to communication and video technology (Ahmed,2019). Mobile sensors and venerable technology are interconnected (Nath et al., 2017; Wang et al., 2020) and are a reinforcing loop. Mobile sensors and wearable technology work together to improve each other's reliability (Ammad et al., 2021; Wang et al.,2020). Mobile Apps are connected to drones and uncrewed aerial vehicles (Maali et al., 2024), and drones and uncrewed aerial vehicles form a reinforcing loop. Building Information Modelling, Virtual Reality, and Augmented Reality are interconnected (Maali et al., 2024); Virtual Reality and Augmented Reality form a reinforcing loop. Reinforcing loops represent factors supplementing each other. Similarly, BIM, UAVs, and drones work together to improve H&S. UAVs and drones are aided by mobile applications to improve their effectiveness (Zulu & Muleya, 2018). BIM also combines with virtual and augmented reality to produce the best results. However, the literature review also revealed that ST is not available commonly for the following (which combinedly form around 40 % of factors referred by authors:

- Adverse Weather Conditions
- Vibrations
- Violence
- Legislative
- Financial
- Social
- Cultural Training Communication
- Disease and illness

- Fire and Explosion
- Over Exertion
- Suicide
- Physiological factor

Legislative, Financial, Social, Suicide, and Physiological factors may be out of reach of ST at present due to its complexity, expertise and influence on construction professionals. However, adverse Weather Conditions, Vibrations, Violence, Disease and illness, Fire and Explosion, and Over Exertion can be specifically targeted for future SMART technology research. SLR reveals that current digital developments profoundly help improve H&S within construction. It has revolutionised every aspect of the construction business, and with the continued advancement of technology, the future looks promising. The stakeholder group that benefits directly from these improvements are the employees. Due to their direct involvement as workers, they would be of utmost priority. Evidence has suggested that long-term employee benefits are happiness and a morale boost (WORKSAFE, 2021). When H&S measures are not in place to protect the workers, the business is accountable under the law and could face heavy fines. This would have a domino effect on the business's operations, which could cause it to be deregistered and unable to be productive and make a profit. A business's costs are much higher when H&S measures are neglected. Also, the complexity of a construction business involves more than the business itself, as a project can draw in third parties like contractors, subcontractors, suppliers and professionals like architects, engineers, project managers, quantity surveyors and the like, and they will be at the site at some stage of the project. Their work will also be made more accessible and more efficient with the help of technology. However, when those directly involved with the project are not protected, the risks and harm are much more significant.

Clients or investors are the next groups affected by the improved technology. As projects require much capital to commence, investors rely on the investment to fruition; thus, they place a tremendous amount of trust in the business they have contracted to carry out the work. However, as stated earlier, if parties directly affected by the work are in danger or harmed, the work will not be delivered. The technology not only supports their H&S but also allows clients or investors to keep track of the project's progress in real-time, as well as the ability to make changes or improvements. For instance, drones can monitor construction sites for potential hazards, and virtual reality can be used for safety training. Society is the final group to benefit from using technology as an H&S measure within construction. They will be economically advantageous as a substantial correlation exists between our country's overall productivity and GDP. Setting a high standard for H&S in construction is not only expected by law but also a social responsibility, and businesses must show the public that they care and prioritise the H&S of people first, and only then can profit follow suit.

SMART technology incorporated into the construction industry depends on various factors, such as the trust between construction professionals and technological developers, which helps the transition to adoption. Another factor is the technical advancement factors, where all the stakeholders should be willing to embrace changes as more advanced ST would be innovated over time. Though there could be a willingness to adopt technology into the construction industry, its sustainability will be crucial among the various stakeholders. These factors lead to the challenges of adopting SMART technology into the construction industry, including but not limited to the high initial investment, the need for retraining and upskilling of the workforce, and the potential resistance to change. Apart from the construction professionals, the other key stakeholders (taxpayers and the government) who fund and care for the H&S aftereffects need to be involved in adopting SMART technology into the construction industry. The privacy security and risks involved in using SMART technology in the construction industry affect not only organizations and the government but also the well-being, quality of life and regulations concerning the citizens. Therefore, to have functional SMART technology offering services in the construction industry, there is a need to set standards and protocols to check the quality and adherence to set rules, and by doing so, the mobility of the SMART technology will be enhanced.

5. Conclusion

A country's economic and social well-being relies heavily on health and safety (H&S) in the construction sector, affecting many stakeholders. This review article examines the factors that impact H&S and the use of SMART Technologies (SM) to mitigate risks in the industry. The selected papers highlight the need for intelligent technologies to minimize injuries, illnesses, and severe harm in construction and encourage readers to consider their implementation. One hundred forty-five journal articles for H&S factors and 87 ST journal articles were discussed in this SLR (refer to Table 3 and Table 4). Five major databases, Google Scholar, Scopus, Science Direct, and Emerald Insight, were used to search and extract the crucial article list. This review article highlighted the factors affecting H&S (H&S) and the ST (SM) used to mitigate them in the Construction Industry to encourage readers and potential construction audiences to consider the need for intelligent technologies to minimise the risks of injuries, illnesses, and severe harm in the construction industry. The SLR critically identified "fatal or focus five" factors (FFH/objects and trapped between objects; FTS; Machinery/Equipment Malfunction and Moving Equipment; Pollutants: Chemicals, Airborne Dust, Asbestos; and Electrocution) that for 60% of factors search. The ST includes Safety Boots/SMART Glasses/SMART Helmet/SMART Vests/SMART PPE/SMART Watch, Mobile Apps, Building Information Modelling (BIM), Virtual Reality/Augmented Reality, Drones/ Unmanned Aerial Vehicles, and Wearable Technology/Mobile Sensors were identified as tools that mitigate the risk posed by "Fatal five".

Further, the SLR highlighted that other factors within the scope of ST, such as Weather Conditions, Vibrations, Violence, Disease and illness, Fire and Explosion, and Over Exertion, are yet to be adopted in the field. The paper's originality is that it is the first to highlight all factors affecting H&S and ST interactions that help mitigate associated risks and identify the critical "Fatal five" factors; further, it identified factors within the ST scope that are yet to be explored.

5.1. Limitations

SLR methodology limitations of not obtaining the most updated field knowledge are critical and are offset by choosing 72% of H&S and 92% of SM review literature post-2017. Limitations to capturing articles because of the restriction of database access: only English language search and journals that are not a part of the databases selected are acknowledged. However, key database search that recognises rigorous peer-reviewed articles offset these limitations. The researcher's Bias is acknowledged.

5.2. Practical and Theoretical Implications

This article highlights the construction of H&S factors and their interlinks with ST that aid in mitigating associated risks. The article establishes the Fatal five and trivial 15 factors, which would help construction managers prioritise H&S risks. Further, the connectivity of ST discussed would aid the organisation's overall H&S management. The practical and theoretical implications contain an improved understanding of all factors affecting H&S and ST that are accessible to help mitigate risks. The tactical managers could use the ST to decrease H&S risks during construction. This article on H&S and ST and relationships can theorize that the construction industry is more likely to identify clear root causes of H&S and related ST than previously. Practical implications are high, as using such SMART technologies would improve the economic consequences through injury prevention, increasing productivity, and cost reduction. The theoretical implications include a greater understanding for academics on H&S factors, ST and gaps in ST concerning H&S, which can be expanded to provide new insights into existing knowledge.

5.3. Future Research

This SLR reveals a lack of knowledge and commercialisation of ST, specifically for adverse Weather Conditions, Vibrations, Violence, Disease and illness, Fire and Explosion, and Exertion. These could be the basis and direction for future research in ST. This paper provides theoretical insights and additional empirical work to complement them, which could be potential future research. The paper identified "Fatal five" risks and SMART technology adoption gaps. However, future research with real-world data to support the argument will strengthen and add to the knowledge.

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SMART Technologies that Influence Construction Health & Safety Factors Risk Reduction in The Current Digital Era

Abstract

Purpose – This article aims to highlight the factors affecting health and safety (H&S) and the SMART Technologies (ST) used to mitigate them in the Construction Industry through a range of selected papers to encourage readers and potential audiences to consider the need for intelligent technologies to minimise the risks of injuries, illnesses, and severe harm in the construction industry.

Design/Methodology/approach – This paper adopts a double systematic literature review (SLR) to analyse studies investigating the factors affecting H&S and the ST in the construction industry using databases such as Google Scholar, Scopus, Science Direct, and Emerald Insight publication.

Findings – The SLR identified "fatal or focus five factors" that include objects Fall from heights (FFH) and trapped between objects; Falls, Trips, and slips (FTS); Machinery/Equipment Malfunction and Moving Equipment; Pollutants: Chemicals, Airborne Dust, Asbestos; and Electrocution. The ST includes Safety Boots/SMART Glasses/SMART Helmet/SMART Vests/SMART PPE/SMART Watch, Mobile Apps, Building Information Modelling (BIM), Virtual Reality/Augmented Reality (VR/AR), Drones/ Unmanned Aerial Vehicles, and Wearable Technology/Mobile Sensors help mitigate the risk posed by "Fatal five". However, other factors within the scope of ST, such as Weather Conditions, Vibrations, Violence, Disease and illness, Fire and Explosion, and Over Exertion, are yet to be adopted in the field.

Originality/Value- This paper highlights all factors affecting H&S and ST that help mitigate associated risks and identifies the "Fatal five" factors. The paper is the first to highlight the factors affecting H&S combined with ST in use and their interactions. The paper also identified factors within the ST scope that are yet to be explored.

Practical and Theoretical implications: This article unravels the construction H&S factors and their interlinks with ST, which would aid industry understanding and focus on mitigating associated risks. The article highlights the Fatal five and trivial 15, which would help better understand the causes of the H&S risks. Further, the paper discusses ST's connectivity, which would aid the organisation's overall H&S management. The practical and theoretical implications include a better understanding of all factors that affect H&S and ST available to help mitigate concerns. The operating managers could use the ST to reduce H&S risks at every construction process stage. This article on H&S and ST and relationships can theorise that the Construction industry is more likely to identify clear root causes of H&S and ST usage than previously. The theoretical implications include enhanced understanding for academics on H&S factors, ST, and gaps in ST concerning H&S, which can be expanded to provide new insights into existing knowledge.

Keywords- Construction, H&S, Construction Risk, ST, SMART construction, Construction H&S

1. Introduction

The construction industry significantly contributes to UN sustainability Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. The construction industry, a key player in economic growth, aids in growing any country's economy (Nawi et al., 2016), investing nearly $10 trillion annually in goods and services related to construction (Awolusi et al., 2018). Despite being crucial to economic expansion, the construction industry is precarious due to its hazards and unpredictability (Ghodrati et al., 2018), with a high rate of injury and mortality worldwide (Ghodrati et al., 2018). It is concerning that the industry has yet to address H&S effectively. Even the UN sustainability program, a crucial global initiative, does not address Industrial H&S concerns. The closest it comes is target 3.9, which states, "By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination." The target 3.6 States, "By 2020, halve the number of global deaths and injuries from road traffic accidents". However, it has not yet addressed Industrial accidents.

The New Zealand (NZ) WORKSAFE department report highlights that between September 2020 and August 2021, 561 Construction-related injuries, illnesses and severe harm cases were recorded, making the construction industry the most dangerous in NZ (WorkSafe New Zealand, 2021). Construction employees actively participating in the construction process were at a greater mortality risk than individuals working in other fields (Abas et al., 2016). The nature of the construction industry has led to significant inefficiencies in project performance, with construction-related injuries causing project completion delays, increased project costs, decreased productivity, and the development of passive organisational perceptions. These statistics underscore the urgent need for safety improvements in the construction industry. Figure 1 shows NZ's industries with the highest injuries, illnesses, and severe harm (WORKSAFE, 2021).

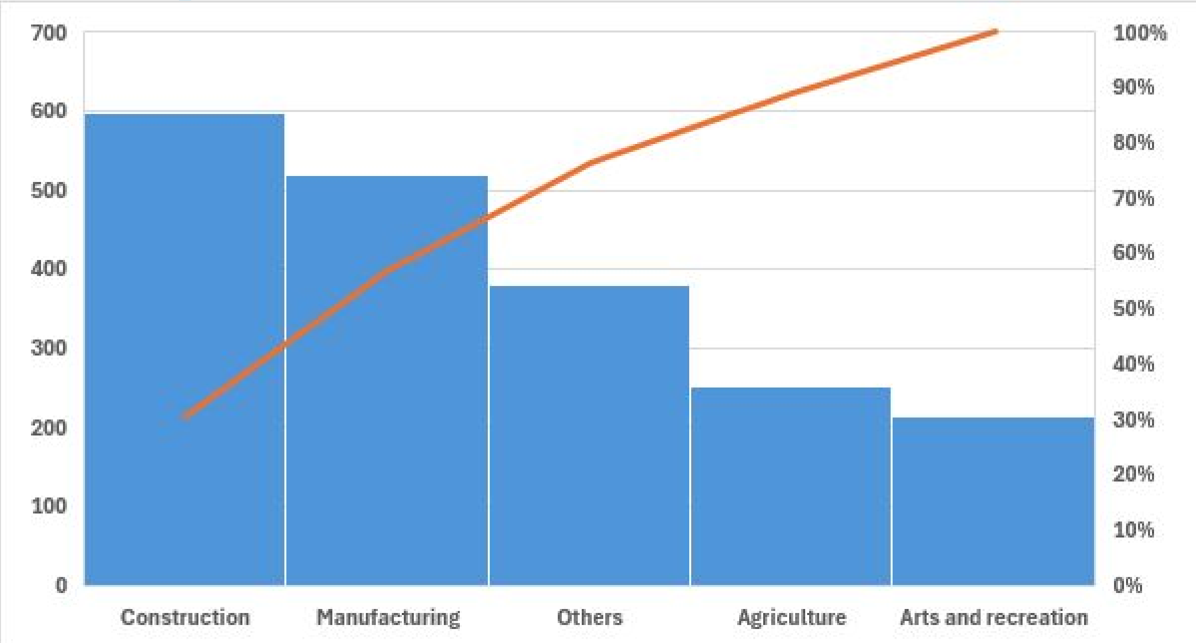

Figure 1: Industries with the highest numbers of injuries, illnesses and severe harm Source: Authors own work

BigRentz (2022) states that 1,061 people lost their lives while doing their jobs in 2019 alone, and there were more than 195,600 incidents of on-the-job injuries. Construction sites account for one-fifth of worker fatalities in the US, making it the fourth most fatality-prone sector (B.L.S, 2022). Also, Ali et al. (2017) report for the Department of Occupational Safety and Health (DOSH) in Malaysia states that the construction industry in 2017 had the most workplace accidents by sector, with 15 deaths out of 70. The frequency of occurrences affecting workplace safety and health that ended in harm or death over the last five years ending 2014 has substantially increased (Chong & Low, 2014). Large construction projects in New York have exposed workers to hazardous conditions, increasing the risk of accidents and degrading the safety performance of the projects (Chong & Low, 2014). Nadhin et al. (2016) reported that falls are the leading cause of serious injuries (48%) and fatalities (30%) of all construction accidents. FFH represent over one-third of construction injuries, leading causes of multi-serious injuries and fatalities. In 2013, FFH accounted for 36.9% of occupational fatalities in the United States, 31% in the United Kingdom, and 12% in Australia. In 2019, 50.1% of deaths across all industrial sectors were caused by FFH, being struck by an object, and collisions occurred on construction sites in Korea (Kim et al., 2020). 41.2% of these fatalities were found to be head injuries. Even though most workers on construction sites know how necessary the safety helmet is, approximately 60% of them do not wear it correctly or refuse to wear it because of discomfort, leading to injuries and fatalities (Kim et al., 2020).

The construction industry is a significant source of employment in New Zealand and contributes more than 6% to the country's GDP Hall et al. (2022). However, due to its large size, it also has a significant share of work-related accidents and illnesses. In 2020, Stats NZ reported 34,404 claims within the sector, highlighting the importance of H&S in construction (Stats NZ, 2021). According to Kim et al. (2020), FFH resulted in 300,000 injuries and 818 fatalities in the United States in 2014, making it the second-highest cause of occupational accidents. Smith (2024) reports that FFH accounts for one-third of all construction-related accidents in the United States. From 2011 to 2016, fatalities caused by FFH increased by 26%. In Great Britain, FFH was responsible for 40 out of 147 construction site fatalities between 2018 and 2019, making it the highest fatality rate in construction sites. Similarly, New Zealand also experiences a significant number of falls from height. Figure 2 shows the FFH incidents in New Zealand between Jul 2022 and Jun 2023.

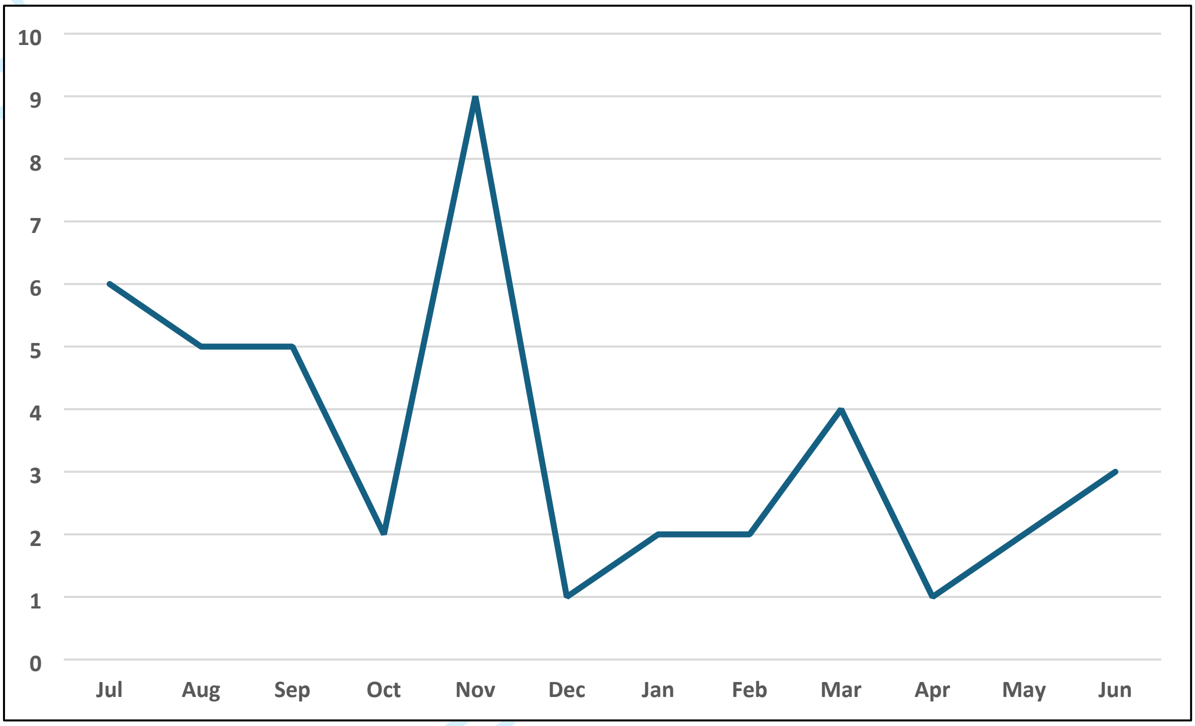

Figure 2: FFH (WorkSafe NZ, 2023) Source: Authors own work

Furthermore, according to Worksafe (2021), asbestos-related diseases claim more than 200 NZers' lives yearly, a significant concern that needs to be addressed (Lessing et al., 2017). H&S is the responsibility of employers and employees, and organisations exist to ensure the safety and health of employees (Edgar et al., 2017; Peace, 2017). Construction accident causes are influenced by the industry's unique working processes, human behaviour, unsafe work practices, equipment, and procedures. These factors contribute to poor safety management (Charehzehi & Ahankoob, 2012); employers must equip their employees with the necessary skills and knowledge, continually increasing safety standards in building projects to mitigate potential dangers. There are many human factors, such as negligence, failure to obey work procedures, failure to use personal protective equipment (PPE) (Nawi et al., 2016) and physical factors, such as equipment without safety devices, poor site management, harsh work operation (Shamsuddin et al., 2015) that leads H&S hazards. These factors could lead to accidents, further delaying work and reducing productivity (Mohammadi et al., 2018b). Therefore, every business must provide rigorous training and safety procedures (Charehzehi & Ahankoob, 2012) that may continually increase safety standards in building projects to mitigate potential dangers. Hence, workplace safety and health must be addressed to avoid accidents (Abas et al., 2020), probably correlating to the latest technologies. It is crucial to evaluate the level of safety among all people who work at the site, which is constantly impacted by many circumstances (Brauer, 2022).

Various governments across the globe have legislations that aim to protect workers' H&S. For example, according to BRANZ, the H&S at Work Act (HSWA) of NZ requires that: "All businesses, regardless of size, engage their staff in safety issues. The Act focuses on managing critical risks and taking actions that reduce workplace harm" (HSWA, 2015). Before they escalate, this proactive approach to managing risks should reassure the audience. If improvements are to be made, the safety of the building industry in NZ must be given substantial consideration. Therefore, the importance of H&S can be summed up as a government initiative to enforce the awareness of the risks associated with the construction and implement the appropriate precautions to prevent deaths and decrease injuries. The NZ government has imposed legislation, such as the Control of Substances Hazardous to Health regulations, agencies, and regulatory authorities, such as MBIE and Work Safe, to ensure that H&S measures are monitored and carried out in the workplace. This is because this industry is particularly prone to accidents and injuries. All H&S regulations and guidelines in NZ are based on the H&S at Work Act (HSWA) 2015; this act is intended to provide a balanced framework for safeguarding the H&S of workers and workplaces (Dabee, 2020). According to WorkSafe NZ, the H&S at Work Act 2015 sets out the purpose of HSWA (WorkSafe NZ, 2019). The introduction of the HSWA was a statutory requirement for designers to bring stakeholders into the equation through the mitigation of H&S risks from the cradle to the grave, known as Safety in Design (Guo & Li, 2021).

A proper H&S system has numerous advantages, such as fewer accidents, less damage to property, less downtime, better morale, better interactions amongst workers, more productivity, cheaper costs, and better quality (Vincoli, 2024). Other benefits include lower insurance costs, fewer hidden expenditures, excellent supervisor morale, productivity, and improved marketability (Cooney, 2016). Kuta et al. (2021) reported that research by the European Foundation for the Improvement of Living and Working Conditions in Dublin found that the social costs associated with fewer employee musculoskeletal disorders equal around 15% of the costs associated with workplace accidents. It should be emphasised that around 33% of manual workers in the European Union experience back and spinal pain, nearly 23% of respondents report feeling generally tired, and roughly 13% experience hand overload (Kuta et al., 2021). In contrast to other professions, the pressure on the musculoskeletal system may be 16% higher in construction environments (Kuta et al., 2021).

The International Labour Organization (2005) estimated that at least 60,000 fatal accidents occur on construction sites yearly. However, numerous studies and reports prove that safety management effectively reduces construction death and injury rates and substantially benefits society and enterprises. The casualties from these accidents result in significant economic losses to the community. For instance, the International Labour Organization (2005) reported that construction accidents account for 4% of the global Gross Domestic Product. These accidents also impact the economies of countries that use advanced safety management. However, enterprises can be particularly interested in the fact that they can effectively enhance their economic benefits by adopting reasonable safety management methods. They reported that almost half of the companies showed that improving safety management decreased the project schedule by at least one week; approximately 73% of the companies successfully reduced their total investment by 1% to 5% (Harvey, 2013). However, despite efforts, the situation has remained mostly the same since 2005. The Office of National Statistics (2020) of the UK published that the cost of injury only reached 16.2 billion pounds in 2018, accounting for 1% of the GDP in the UK. Despite the ongoing challenges, the economic benefits of safety management are clear.

When accidents occur at construction sites, developers and construction parties often suffer varying losses (Yoon et al., 2013). These losses typically fall into direct and indirect costs (Haupt & Pillay, 2016). It is important to remember that the effects of these accidents can be long-lasting, and understanding the costs involved is crucial for our industry. Haupt and Pillay (2016) stated that direct costs refer to the expenses incurred from treating injuries, and indirect costs are hidden. Most of the time, the insurable costs associated with injuries are the ones the general public knows. Medical bills, premiums for compensation benefits, liabilities, and property damage are examples of direct cost expenditures (Vincoli, 2024). Direct costs are usually calculable with reasonable accuracy (Vincoli, 2024). Understanding the importance of indirect costs resulting from accidents is crucial. They are more difficult to calculate than direct costs, consisting of all non-insurable expenditures incurred by accident (Haupt & Pillay, 2016). Often referred to as "hidden costs," these expenses are not readily apparent and do not have a good history.

Further, the increased risk of injury at work compromises employees' integrity and concerns their families at home. Construction-related fatalities and injuries have had a negative social impact, disrupted work and negatively impacted employee morale, performance, and output Y. Kang et al. (2017). There is also the lengthy process of psychological and emotional support required afterwards. By formalizing safety processes and regulations, workers must be protected against dangers of falling, such as those caused by gaps in the structure that are present either permanently or temporarily or by using unstable materials that do not provide adequate support (Choi et al., 2019). The role of policymakers becomes crucial as they enact and enforce regulations that ensure the safety of workers. Mechanisms for preventing falls have been built into the structure since the 1990s. For example, railing supports and connectors for security wires are created in Australia as a structural system component (Lingard, Cooke, Blismas, et al., 2013). Workers would be more likely to install scaffolds and link safety wires if such facilities existed. However, the accidents and incidents have not fallen to a reasonable level.

Post 2010, various researchers have identified technologies that could assist H&S in the Construction Industry in the new digital era. Multiple studies have aimed to develop cutting-edge technologies and innovative autonomous construction safety surveillance methodologies. Any definition of "SMART building technology" relates to adopting innovations, i.e., healthy, affordable, safe, and comfortable human habitation at all life cycle stages of construction projects (Khlaponin et al., 2020). "Self-Monitoring Analysis and Reporting Technology" is abbreviated as "SMART." In the real world, this technology combines the Internet of Things with artificial intelligence, machine learning, and big data to give real-world devices cognitive awareness (Liu et al., 2017). The development of SMART technology as a wearable provides a channel for results-oriented data collection and analysis (Adjiski et al., 2019). ST has been utilized recently on construction sites to reduce the number of fatalities and injuries brought on by accidents and keep track of unreported incidents (Forat et al., 2021). SMART technology is increasingly being recognized for raising safety standards in the building industry.

Any item can be connected and used as a hub for gathering or transmitting information to a more extensive network under the IoT paradigm, centring on the interconnection of devices or "things" (Miller, 2015; Svertoka et al., 2021). However, some SMART devices can function well without user contact (Svertoka et al., 2021). For SMART gadgets to operate, network connectivity is necessary as the gadget may occasionally join a network and share data with other devices. Silverio-Fernandez et al. (2018) state that a SMART device can be considered a context-aware electronic device capable of autonomous computation and connecting to other devices wired or wirelessly for data exchange. The world is rapidly evolving and increasingly using ST due to exponential innovation in computing hardware, communication software, and technical applications (Edirisinghe,2019). This paradigm shift has occurred from mobile computing to pervasive computing to ST with embedded intelligence (Edirisinghe, 2019). This review aims to identify and examine the critical variables affecting H&S in the construction sector and mitigate the risks using innovative technologies. The review worked on the Research question:

How does the ST influence H&S factors' risk reduction in the current digital era in the construction industry?

2. Method

SLR is adopted to answer the research question. An SLR methodology has positives and limitations. Based on pre-specified eligibility criteria, SLR helps identify, evaluate, and answer a specific research question by amalgamating all the empirical evidence (Creswell and Creswell (2023). SLR is not location-dependent and primarily uses online resources. Secondly, online SLR helps researchers refine the search as much as required. The process used was similar to Pedrini and Laura (2019). The SLR had inclusion and exclusion criteria, as listed in Table 1.

Table 1 Inclusion and exclusion criteria.

Inclusion Criteria	**Exclusion Criteria**
Construction: Discipline: Engineering, Subdiscipline: Building Construction	Not in construction
H&S in construction	Not in H&S
Risk, accident, or injury in construction	Not related to risk, accident, or injury in construction
Prevention of risk, accident, or injury in Construction	Not related to the prevention of risk, accident, or injury in construction
ST in construction H&S	Not related to ST in construction H&S
ST in the prevention of H&S Risk, accident, or injury	Not related to ST in the prevention of H&S Risk, accident, or injury
Written in English	Written in languages other than English
Major databases	Small databases
Academic articles	Websites and pages

Source: Authors own work

PRISMA checklist-based SLR has been carried out for this research. Relevant past literature has been gathered from five domains that included databases of Google Scholar, ScienceDirect, Scopus, and publisher Emerald Insight using two keyword combinations to identify the factors affecting H&S in the construction industry and the ST to mitigate the identified H&S risks. The three databases are chosen due to their credibility and popularity. Emerald Insight publication was added to the search due to its diversity and credibility in publications. Significant time was spent reading and analysing articles, reviewing, structuring, and writing, and published articles were updated periodically. The SLR aims for sufficient coverage of specified topics and concepts; the researchers regularly discuss the topics and contents to be included and excluded with their colleagues from Architecture, Engineering, Construction and Projects and incorporate their suggestions. Organisation-linked Google Scholar, Emerald, Science Direct, and Scopus search gave access to many articles globally and helped follow the newest publications in construction H&S and ST. The occurrence of keywords showed that many connections could be derived from reading the articles and understanding the factors. Though no protocol was prepared for the review, keywords were used for the search. The keywords used and search results are shown in Table 2.

Table 2: Literature search results

Databases	Selection Criteria	
	Without filters	**Discipline: Engineering Subdiscipline: Building Construction Year: from 2012**
Keyword Combination 1	**TITLE-ABS-KEY ("construction" AND "H&S" OR "H&S" AND "risk" OR "accident" OR "injury")**	
Scopus	271	148
Emerald Insight	1743	58
ScienceDirect	443	31
Google Scholar	1450	94
Keyword Combination 2	**TITLE-ABS-KEY ("construction" AND "H&S" OR "H&S" AND "risk" OR "accident" OR "injury" AND "prevention" AND "SMART technology")**	
Scopus	134	16
Emerald Insight	255	34
ScienceDirect	365	30
Google Scholar	585	65

Source: Authors own work

After the critical steps of literature identification, screening, and eligibility, 147 papers were selected for the factors affecting the H&S in the construction and 87 papers for the ST. Figure 3 shows the method of literature selection for the factors affecting H&S in the construction industry. Review articles have been excluded to maintain originality.

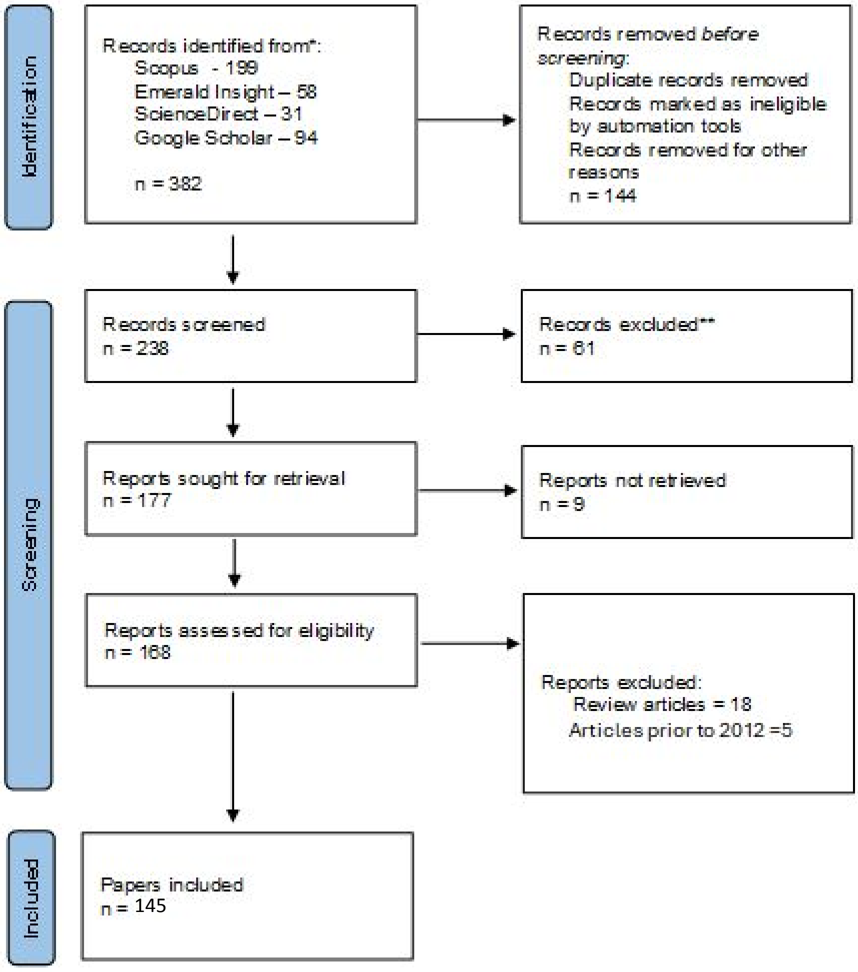

Figure 3: Identification of studies via database search

Source: Authors own work based on Prisma guidelines

Articles published from 2012 to 2021 were searched using four popular databases; each was last searched on December 17, 2022. Though the investigation was from 2012, a few articles of prominence pre-2016 appeared on the list. Subsequent searches for years 2022, 2023 and 2024 during August 2024 yielded six more articles of relevance. Figure 4 shows the number of articles per year, and Figure 5 shows the visualization of H&S articles published based on the countries.

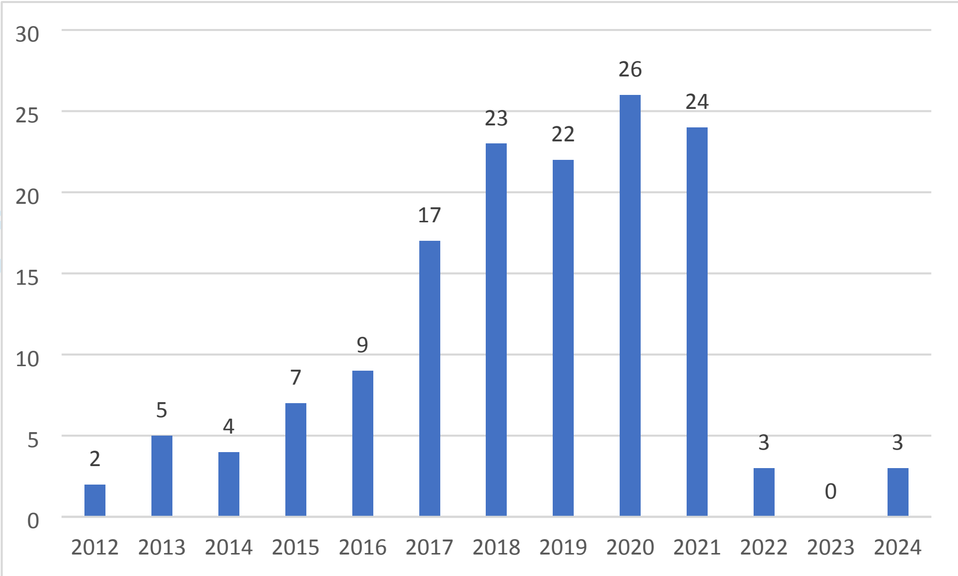

Figure 4: H&S Number of articles year-wise

Source: Authors own work

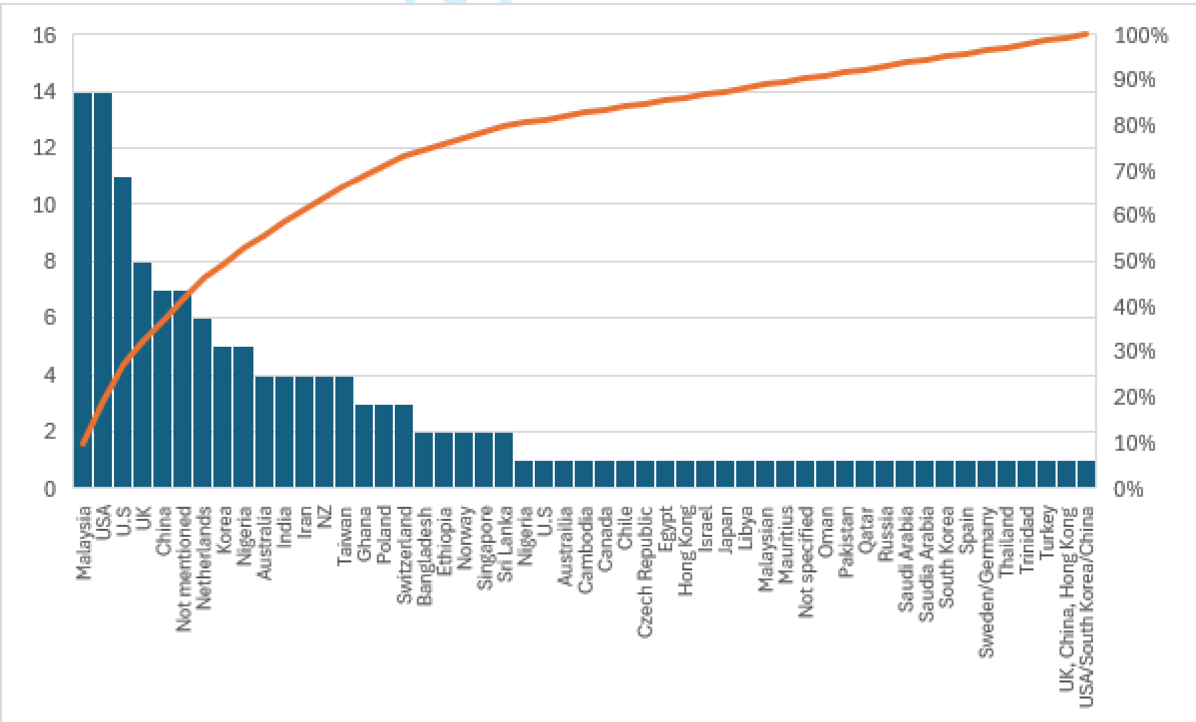

Figure 5: H&S articles published based on the countries

Source: Authors own work ~~*using Vos viewer*~~

Figure 6 shows the method of literature selection for ST in the construction industry. Though the ST search was restricted to Post-2016 to incorporate only the latest digital technology developments, four articles from pre-2016 appeared on the list. The authors chose to keep them on the list due to their relevance and to show the historical perspective. Further search during August 2024 for ST-related papers from 2022 to 2024 did not indicate any new technologies or solutions for H&S in construction. This meant a temporary saturation. Review articles have been excluded to maintain originality. The year spread is shown in Figure 7. Visualization of SMART technology articles published based on the countries is shown in Figure 8.

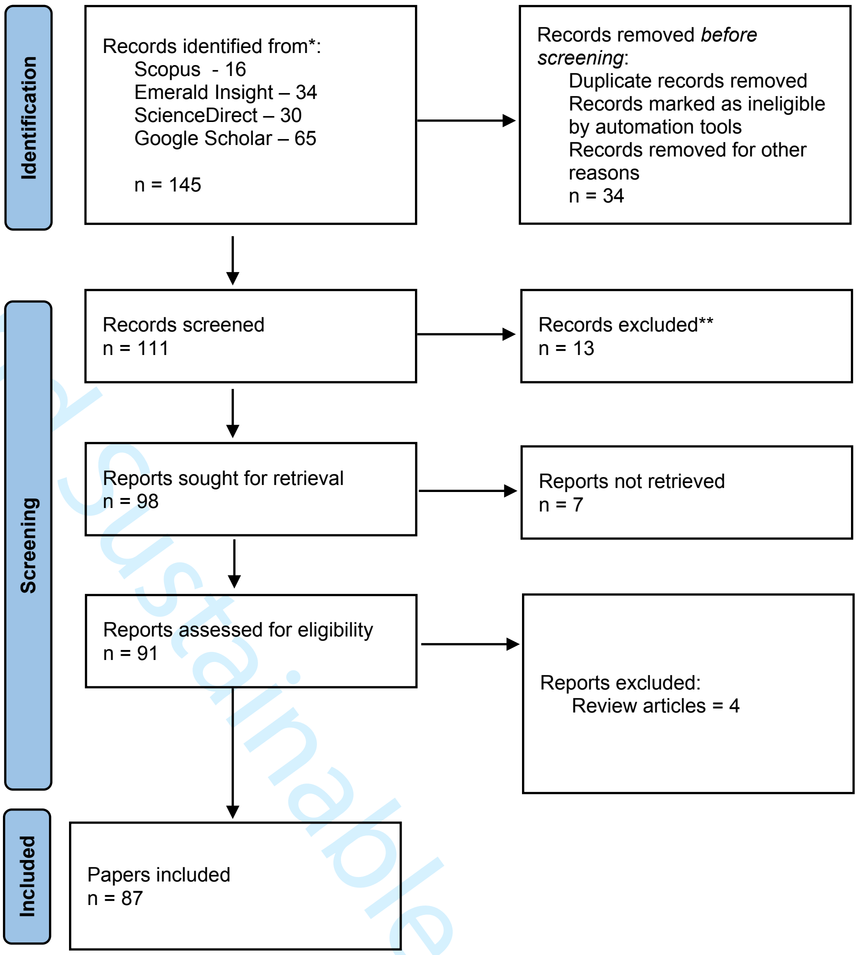

Figure 6:Identification of documents via database search for Keyword combination 2

Source: Authors own work based on Prisma guidelines (Prisma,2024)

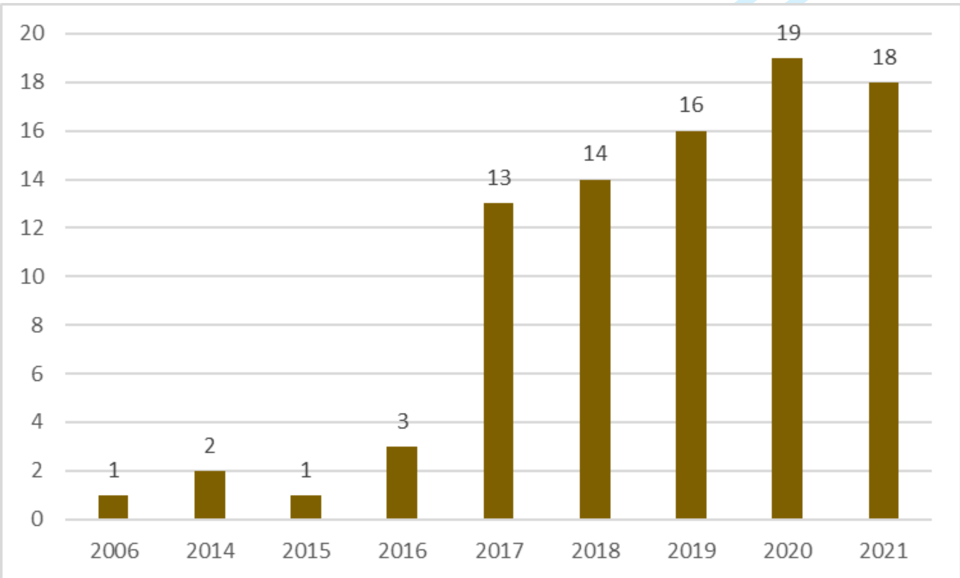

Figure 7: ST number of articles year-wise.

Source: Authors own work

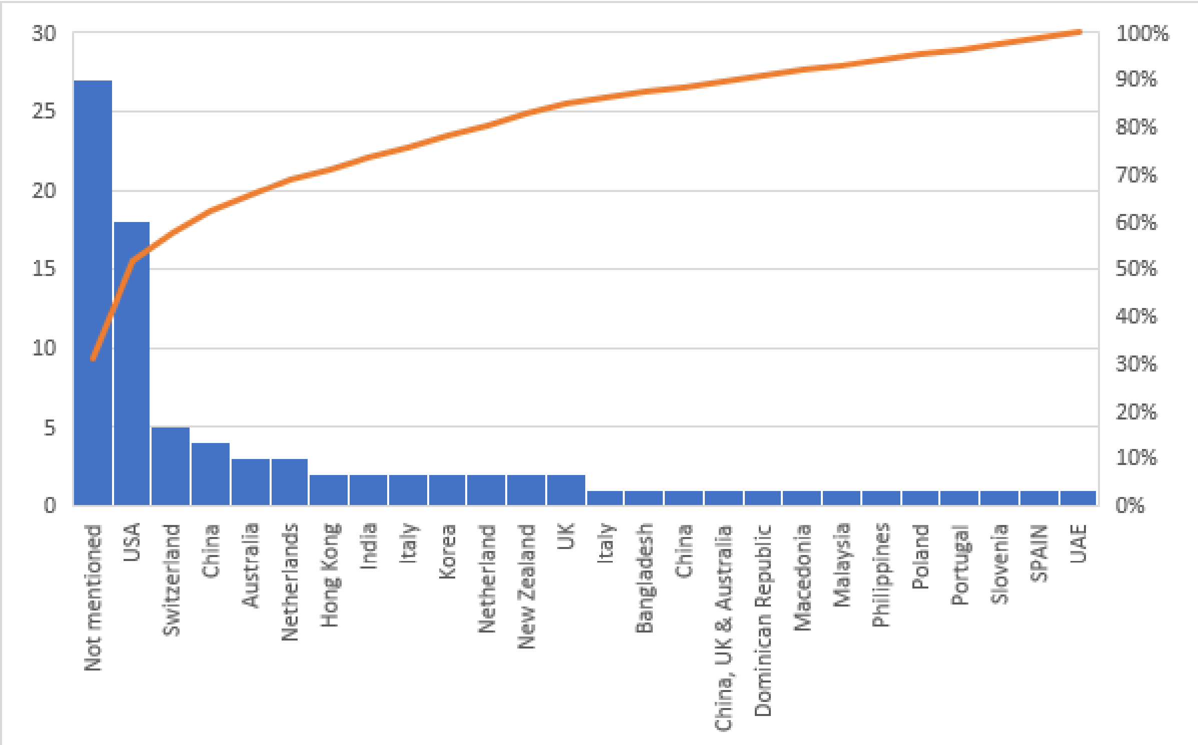

Figure 8 ST articles published based on the countries

Source: Authors own work ~~using VOS viewer~~

The critical journal articles were systematically reviewed using both bibliometric and qualitative methods for analysis. A journal was maintained systematically to detail critical factors and store information from the articles. VOS viewer software, MS Word, Excel, and PowerPoint were used for analysis and results presentation. VOS viewer visualised keyword occurrence and articles published based on the countries. Each of the H&S and ST factors was further studied to identify their interlinks. The articles were read at least twice to understand the factors and their interlinks and recorded in an Excel table format in a journal. The H&S factors, ST, all the keywords, connectivity, and polarity were noted in the Excel table. The excel format was then analysed to plot the connectivity between H&S and ST factors using Vensim software. The result of this analysis is presented in a Causal loop diagram.

The Causal loop diagram illustrates the interactions between ST and H&S factors in construction, emphasizing the importance of understanding these interactions. It is crucial to note that ST, when used in isolation, cannot fully mitigate all H&S factors. However, when ST is applied in conjunction, it can significantly mitigate most of the factors that affect H&S. Therefore, understanding these interactions is beneficial and vital for the construction environment. This understanding is essential for identifying gaps in ST concerning the mitigation of H&S factors, thereby enhancing awareness of the need for integrated approaches to safety in construction.

3. SLR - Results

This review aimed to gather and analyse the past literature on the factors affecting H&S and ST in the construction industry. Table 3: Factors affecting H&S in the construction industry. A total of 145 articles revealed the 20 factors affecting H&S in construction.

Table 3: Factors affecting H&S in the construction industry

Item	Author	Origin	Year	Factors affecting H&S in the construction industry																			
				Physiological and psychological factor	Falls, Trips, and slips	Fall from heights/objects, trapped between objects	Electrocution	Machinery/Equipment Malfunction. Moving Equipment	Pollutants. Chemicals, Airborne Dust, Asbestos	Unsafe worksite	Adverse Weather Conditions	Vibrations	Violence	Legislative	Financial	Social	Cultural	Training	Communication	Disease and illness	Fire and Explosion	Over Exertion	Suicide
1	(Abas & Blismas, 2021)	Malaysia	2021		✓	✓	✓	✓	✓	✓		✓									✓		
2	(Abas et al., 2020)	Malaysia	2020	✓	✓	✓	✓	✓	✓	✓	✓												
3	(Abas et al., 2021)		2020						✓		✓							✓					
4	(Asilian-Mahabadi et al., 2020)	Iran	2020							✓													
5	(Agbolosu–Amison & Acheampong, 2021)	Ghana	2021		✓																		
6	(Agyekum et al., 2018)	Ghana	2018							✓													
7	(Ahmed, 2019)	Bangladesh	2019					✓		✓												✓	
8	(Asanka & Ranasinghe, 2015)	Sri Lanka	2015			✓					✓								✓			✓	
9	(Ashuro et al., 2021)	Ethiopia	2021		✓																		
10	(Atique et al., 2012)	Qatar	2012			✓																	
11	(Awolusi et al., 2018)	USA	2018	✓	✓	✓	✓	✓	✓	✓	✓												
12	(B. Choi et al., 2019)	Netherlands	2019	✓																			
13	(B. G. Kang et al., 2017)	USA	2017			✓	✓												✓				
14	(Bangaru et al., 2020)	Switzerland	2020	✓																			
15	(Newaz et al., 2022)	Australia	2022		✓	✓																	
16	(Betit et al., 2017)	USA	2017																				
17	(Birabakaran & Nagapan, 2021)	Malaysia	2021					✓															
18	(Brolin et al., 2021)	Sweden/Germany	2021		✓																		
19	(Brum, 2020)	Malaysia	2020	✓				✓					✓					✓					
20	(Sacks et al., 2013)	U.S	2013							✓													
21	(Vincoli, 2024)	Canada	2024			✓	✓		✓												✓	✓	
22	(Carabott, 2015)	Not mentioned	2015											✓			✓	✓					
23	(Carrillo-Castrillo et al., 2017)	Spain	2016		✓																		
24	(Chawdhry et al., 2021)	Bangladesh	2021		✓	✓	✓	✓	✓	✓		✓									✓	✓	
25	(Hwang et al., 2017)	Singapore	2017	✓	✓	✓	✓	✓	✓	✓													
26	(Chen & Demachi, 2021)	Not mentioned	2021			✓																	
27	(Nadhim et al., 2016)	Australia	2016			✓																	
28	(Peng et al., 2014)	Taiwan	2014			✓																	
29	(Zhao et al., 2016)	Taiwan	2016				✓				✓											✓	
30	(Chi et al., 2012)	Taiwan	2021				✓	✓															
31	(Cho et al., 2018)	USA	2018			✓																	
32	(Choi & Carlson, 2014)	USA	2014	✓	✓			✓		✓													
33	(Collins & Spillane, 2020)	UK	2020						✓														
34	(Durdyev et al., 2017)	Cambodia	2017		✓	✓																	
35	(Williams et al., 2019)	Nigeria	2019					✓					✓										
36	(Eskandar et al., 2019)	Not mentioned	2019	✓	✓	✓			✓		✓					✓							
37	(W. Fang et al., 2018)	China	2018			✓																	

Item	Author	Origin	Year	Factors affecting H&S in the construction industry																			
				Physiological and psychological factor	Falls, Trips, and slips	Fall from heights/objects, trapped between objects	Electrocution	Machinery/Equipment Malfunction. Moving Equipment	Pollutants. Chemicals, Airborne Dust, Asbestos	Unsafe worksite	Adverse Weather Conditions	Vibrations	Violence	Legislative	Financial	Social	Cultural	Training	Communication	Disease and illness	Fire and Explosion	Over Exertion	Suicide
38	(Murray et al., 2013)	U.S	2013		✓	✓	✓	✓	✓			✓									✓		
39	(Brauer, 2022)	U.S	2022		✓	✓	✓	✓	✓	✓		✓									✓		
40	Gelmini et al. (2020)	U.S	2020			✓																	
41	(Jaafar et al., 2018)	Malaysia	2018			✓	✓														✓	✓	
42	Ghimire and Neupane (2020)	UK	2020																	✓			
43	(Allen & Iano, 2019)	U.S	2019								✓												
44	Giri (2020)	India	2020					✓	✓	✓													
45	Glass et al. (2017)	NZ	2017						✓														
46	Goh et al. (2016)	Malaysia	2016			✓					✓												
47	Guo et al. (2019)	Not mentioned	2019	✓					✓														
48	(Abu Aisheh et al., 2022)	Malaysia	2022			✓					✓												
49	Hamid et al. (2019)	Malaysia	2019		✓																		
50	Han et al. (2013)	Malaysia	2021			✓																	
51	Hashem et al. (2013)	Libya	2013	✓	✓	✓									✓			✓					
52	(Guo et al., 2016)	USA	2016	✓	✓	✓	✓	✓	✓	✓		✓											
53	Hemler et al. (2020)	USA	2020		✓																		
54	Hoła et al. (2017)	Poland	2017							✓													
55	Hosseini et al. (2020)	Iran	2021				✓																
56	Howard (2017)	USA	2017					✓															
57	Ichikawa (2018)	Japan	2018				✓																
58	Idoga (2020)	Nigeria	2020		✓	✓	✓																
59	(Ijaola et al., 2021)	Nigeria	2021		✓	✓	✓	✓	✓	✓											✓	✓	
60	Ismail and Ghani (2012)	Malaysia	2012		✓	✓	✓	✓															
61	(Woźniak & Hoła, 2024)	Poland	2024			✓	✓																
62	Kambadur (2020)	NZ	2020		✓	✓				✓													
63	Kambadur (2020)	India	2015		✓		✓	✓		✓													
64	Kang and Ryu (2019)	Korea	2019			✓																	
65	Kantova (2017)	Czech Republic	2017										✓										
66	Kaur et al. (2021)	USA	2021																				
67	Kazar and Comu (2020)	Turkey	2020																			✓	
68	Khan et al. (2019)	Pakistan	2019		✓		✓																
69	Kim et al. (2018)	Korea	2018					✓													✓		
70	J. H. Kim et al. (2021)	Switzerland	2021		✓			✓															
71	Kim et al. (2022)	UK	2021	✓																			
72	Kurien et al. (2018)	Netherlands	2018	✓	✓			✓			✓												
73	Kuta et al. (2021)	USA	2021	✓																			
74	Lai et al. (2019)	UK, China, Hong Kong	2019																				
75	Lamm et al. (2017)	NZ	2017		✓	✓				✓													
76	(Fang et al., 2015)	UK	2015																			✓	

Item	Author	Origin	Year	Factors affecting H&S in the construction industry																			
				Physiological and psychological factor	Falls, Trips, and slips	Fall from heights/objects, trapped between objects	Electrocution	Machinery/Equipment Malfunction. Moving Equipment	Pollutants. Chemicals, Airborne Dust, Asbestos	Unsafe worksite	Adverse Weather Conditions	Vibrations	Violence	Legislative	Financial	Social	Cultural	Training	Communication	Disease and illness	Fire and Explosion	Over Exertion	Suicide
77	Lee et al. (2019)	Korea	2019					✓															
78	Lee et al. (2020)	U.S	2018			✓		✓	✓	✓		✓											
79	Leon-Kabamba et al. (2018)	Singapore	2018																	✓			
80	Lette et al. (2018)	Ethiopia	2018		✓																		
81	Li et al. (2019)	China	2019					✓															
82	Li et al. (2021)	Not mentioned	2020						✓														
83	Lingard et al. (2017)	UK	2017																	✓			
84	Liu et al. (2019)	NZ	2019	✓	✓	✓	✓	✓	✓	✓													
85	Martin et al. (2021)	Trinidad	2021																				
86	Martinez et al. (2020)	Chile	2020					✓															
87	McGuinness et al. (2019)	U.S	2019		✓	✓	✓																
88	Milner et al. (2019)	Australia	2019																				✓
89	Mizzi (2019)	UK	2019						✓														
90	Moda et al. (2019)	Nigeria	2018						✓														
91	(Kalteh et al., 2021)	Iran	2021										✓									✓	
92	Mohammadi et al. (2018a)	Iran	2018								✓											✓	
93	Mohd Amir Shazwan and Ee (2018)	Malaysia	2018																				
94	Morrissey et al. (2021)	Not mentioned	2021								✓									✓			
95	Moshashaei et al. (2017)	Norway	2017					✓													✓		
96	Mostly (2022)	Saudia Arabia	2019																				
97	Nadhin et al. (2016)	Switzerland	2016		✓	✓					✓												
98	Namian et al. (2021)	U.S	2021			✓		✓															
99	Nath et al. (2017)	Netherlands	2017	✓					✓														
100	(Zhang et al., 2015)	U.S	2015		✓			✓		✓												✓	
101	Osei-Asibey et al. (2021)	Ghana	2021								✓								✓			✓	
102	Panuwatwanich et al. (2020)	Thailand	2020			✓																	
103	Park et al. (2020)	South Korea	2020				✓				✓											✓	
104	Patel et al. (2021)	U.S	2018					✓															
105	Pedley (2021)	Not mentioned	2021		✓																		
106	(Tadesse & Israel, 2016)	Israel	2016			✓																	
107	Rafindadi et al. (2022)	Malaysian	2020			✓		✓															
108	Rameezdeen and Elmualim (2017)	Australia	2017																			✓	
109	Robert et al. (2018)	U.S	2018					✓					✓										
110	S. D. Choi et al. (2019)	USA/South Korea/China	2019		✓	✓																	
111	(Ramkalawon Veerapen Chetty et al., 2024)	Mauritius	2024		✓	✓	✓	✓	✓	✓		✓									✓	✓	
112	SAMUEL (2019)	Malaysia	2017		✓		✓																
113	Sanni-Anibire et al. (2020)	Saudi Arabia	2019		✓																		

Item	Author	Origin	Year	Factors affecting H&S in the construction industry																			
				Physiological and psychological factor	Falls, Trips, and slips	Fall from heights/objects, trapped between objects	Electrocution	Machinery/Equipment Malfunction. Moving Equipment	Pollutants. Chemicals, Airborne Dust, Asbestos	Unsafe worksite	Adverse Weather Conditions	Vibrations	Violence	Legislative	Financial	Social	Cultural	Training	Communication	Disease and illness	Fire and Explosion	Over Exertion	Suicide
114	(Sacks et al., 2013)	UK	2013								✓											✓	
115	Sazonova et al. (2018)	Russia	2018						✓														
116	Sehsah et al. (2020)	Egypt	2020			✓		✓															
117	Shafique and Rafiq (2019)	Hong Kong	2019		✓																		
118	Shiau et al. (2020)	China	2020				✓																
119	Smith et al. (2014)	USA	2014		✓																		
120	Szóstak et al. (2021)	Poland	2021			✓																	
121	Tamburrini et al. (2020)	India	2020						✓														
122	(Thomas & Sudhakumar, 2014)	India	2014						✓														
123	(Tran et al., 2021)	Korea	2020							✓											✓		
124	Tunji-Olayeni et al. (2018)	Nigeria	2018		✓	✓			✓				✓										
125	Umar and Egbu (2018)	Oman	2018																			✓	
126	Valero et al. (2017)	Netherlands	2020	✓																			
127	Vitharana et al. (2015)	Sri Lanka	2015	✓	✓	✓	✓	✓	✓	✓		✓											
128	Walters and Quinlan (2019)	UK	2018						✓														
129	Williams et al. (2018)	Malaysia	2018		✓				✓														
130	Williams et al. (2019)	Nigeria	2019		✓																		
131	Winge et al. (2019)	Norway	2018			✓	✓	✓															
132	Xiao et al. (2016)	China	2016										✓										
133	Xiong et al. (2019)	China	2019		✓	✓		✓					✓								✓	✓	
134	Xu and Xu (2021)	China	2021			✓																	
135	Y. Kang et al. (2017)	USA	2017		✓	✓	✓	✓															
136	Yan et al. (2018)	Netherlands	2018	✓																			
137	Yang et al. (2016)	Netherlands	2016		✓																		
138	Yang et al. (2017)	U.S	2017		✓	✓		✓														✓	
139	Yang et al. (2020)	USA	2020																		✓		
140	Yang et al. (2021)	China	2021										✓										
141	Yap and Lee (2020)	Malaysia	2020	✓	✓	✓	✓	✓	✓	✓													
142	Yi (2020)	Korea	2020																		✓		
143	Yoon et al. (2013)	Taiwan	2013	✓				✓	✓		✓								✓				
144	Zhao et al. (2015)	U.S	2015	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										
145	Zuo et al. (2017)	Australia	2017						✓														
Totals				**22**	**50**	**54**	**32**	**43**	**34**	**26**	**18**	**9**	**10**	**1**	**1**	**1**	**1**	**4**	**4**	**4**	**14**	**20**	**1**

Source: Authors own work

All the H&S factors that appeared in keywords are selected and visualized in Figure 9. Figure 10 shows the Pareto diagram of factors affecting H&S in construction.

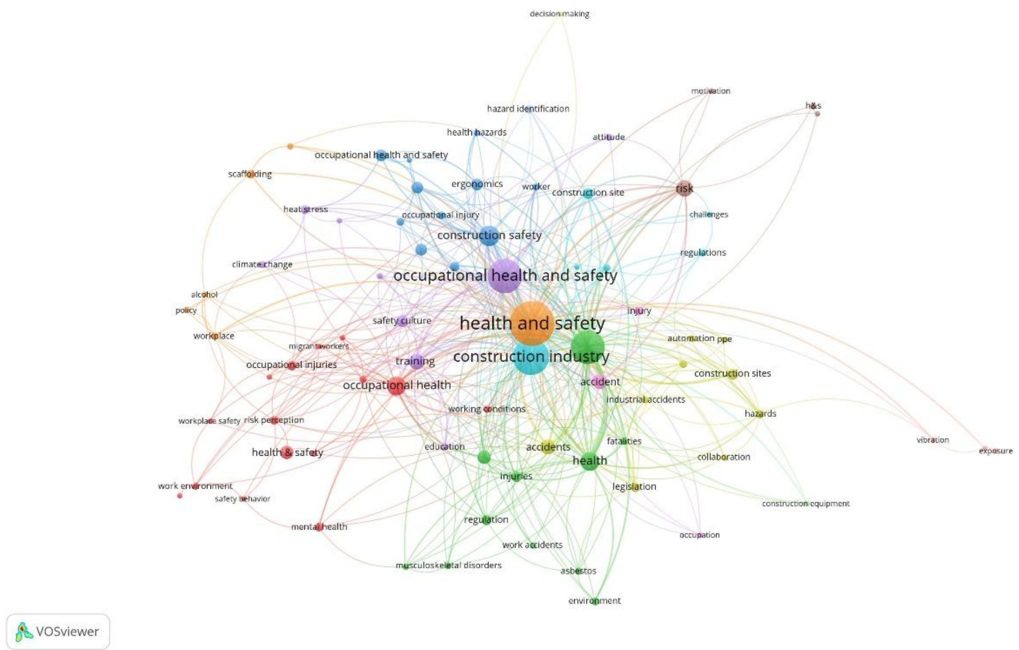

Figure 9:Visualization of keywords occurrence of H&S factors in construction

Source: Authors own work using Vos viewer

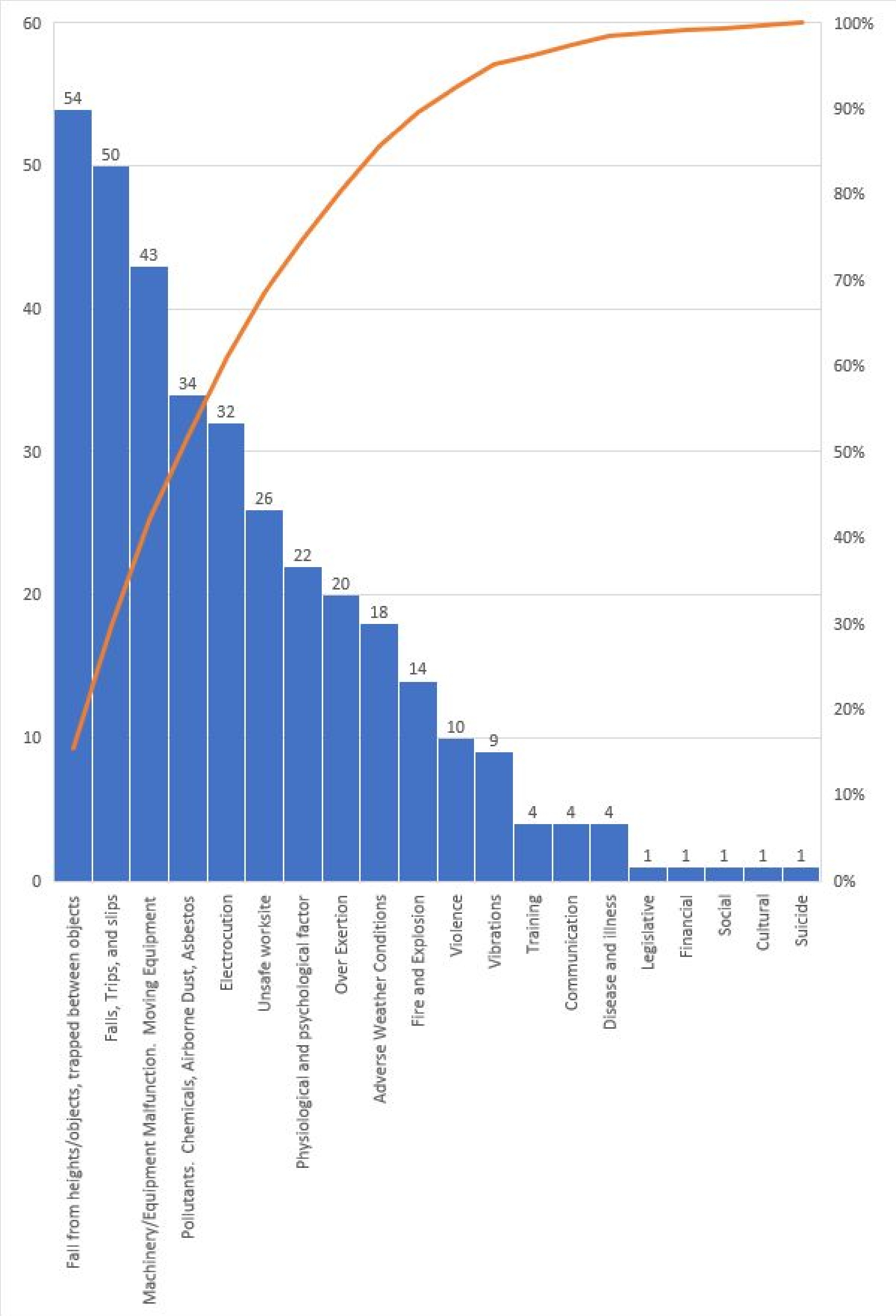

Figure 10 Pareto chart of factors affecting H&S in Construction

Source: Authors own work

Table 4 classified the literature on utilizing SMART technology to mitigate H&S hazards. Figure 11 shows the visualization of the occurrence of keywords in SMART technology concerning H&S in construction. Figure 12 shows the Pareto chart of SMART technology concerning H&S in construction.

Table 4: ST in the Construction Industry

No.	Author	Origin	ST in Construction								
			Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch	Mobile Apps	Building Information Modelling, Virtual Reality, and Augmented Reality	Geofence	Drones/ Unmanned Aerial Vehicles	Wearable Technology/Mobile Sensors	Communication and Video Technology	Robot	Geographic Information Systems
1	Abainza et al. (2020)	Philippines	✓	✓				✓	✓		
2	Adjiski et al. (2019)	Macedonia	✓								
3	Ahmed (2019)	Banglades h		✓		✓			✓		
4	Ahn et al. (2019)	United States	✓								
5	Akinosho et al. (2020)	Netherland			✓		✓			✓	
6	Alizadehsalehi et al. (2020)				✓		✓				
7	Ammad et al. (2021)	Malaysia	✓	✓				✓	✓		
8	Anast et al. (2021)					✓					
9	Antwi-Afari et al. (2019)	Hong Kong	✓								
10	Ashour et al. (2016)	UAE	✓				✓			✓	
11	Ashtekar et al. (2019)		✓								
12	Awolusi et al. (2018)	USA	✓	✓							
13	Azzazy et al. (2021)	NZ	✓								
14	B. Hwang and S. H. Lee (2017)	Netherland s	✓								
15	Baek and Choi (2020)	Korea		✓							
16	Banerjee and Nayak (2021)	Not mentioned		✓	✓						
17	Bangaru et al. (2020)	USA									
18	Barata and da Cunha (2019)	Portugal	✓								
19	Bolshakova et al. (2018)				✓						
20	Callejas Sandoval and Kwon (2019)	USA	✓								

No.	Author	Origin	ST in Construction								
			Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch	Mobile Apps	Building Information Modelling, Virtual Reality, and Augmented Reality	Geofence	Drones/ Unmanned Aerial Vehicles	Wearable Technology/Mobile Sensors	Communication and Video Technology	Robot	Geographic Information Systems
21	Camero-Jurado et al. (2020)	Switzerland	✓								
22	Chan et al. (2020)		✓								
23	Cheng et al. (2019)								✓		
24	Choi et al. (2017)	USA	✓	✓				✓	✓		
25	Ciampa et al. (2018)	Italy					✓				
26	Dogbe et al. (2020)	USA	✓	✓							
27	Edirisinghe (2019)	Australia			✓						
28	Fargnoli and Lombardi (2020)		✓		✓						
29	Ganah and John (2015)	UK		✓	✓				✓		
30	Getuli et al. (2018)	Italy			✓						
31	Gheisari and Esmaeili (2016)	U.S	✓								
32	Guo and Li (2021)	China	✓	✓							
33	Haq (2020)	Australia	✓			✓					
34	Haupt et al. (2019)	Not mentioned	✓	✓	✓					✓	
35	Howard (2017)						✓				
36	Jayasree and Kumari (2020)	India	✓								
37	Jiang et al. (2021)	Netherland					✓			✓	
38	Jiang et al. (2021)				✓						
39	Johansson et al. (2019)		✓								
40	Kang and Ryu (2019)	USA								✓	
41	Kim et al. (2018)	Switzerland	✓								
42	Lee et al. (2020)								✓		
43	Li (2017)	Hong Kong									✓
44	Liu et al. (2019)	NZ		✓					✓		
45	Liu et al. (2021)	USA								✓	
46	Luo et al. (2020)	China	✓	✓							
47	Manzoor et al. (2021)				✓						
48	Marefat et al. (2018)	USA	✓		✓						

No.	Author	Origin	ST in Construction								
			Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch	Mobile Apps	Building Information Modelling, Virtual Reality, and Augmented Reality	Geofence	Drones/ Unmanned Aerial Vehicles	Wearable Technology/Mobile Sensors	Communication and Video Technology	Robot	Geographic Information Systems
49	Márquez-Sánchez et al. (2021)	Switzerland	✓								
50	Martin and Voix (2017)		✓								
51	Mehata et al. (2019)	India	✓								
52	Mordue and Finch (2019)				✓						
53	(Motawa & Kardakou, 2018)				✓		✓				
54	Nath et al. (2017)	USA	✓	✓				✓	✓		
55	Niu et al. (2016)	USA	✓	✓							
56	Nnaji et al. (2021)	Switzerland	✓								
57	Park et al. (2017)	USA	✓	✓							
58	Parn et al. (2019)	UK	✓								
59	(Podgorski et al., 2017)	Poland	✓								
60	Q. Fang et al. (2018)		✓								
61	Rajendran et al. (2020)	Netherlands	✓								
62	Rey-Mercvhan et al. (2021)	Switzerland	✓								
63	(Maali et al., 2024)	USA	✓	✓	✓	✓		✓	✓		
64	Riaz et al. (2014)	Australia			✓						
65	Robert et al. (2016)	USA	✓								
66	Roofigari-Esfahan et al. (2021)		✓								
67	S. Hwang and S. Lee (2017)	United States	✓								
68	Sanchez et al. (2021)	SPAIN	✓			✓					
69	Shafiq et al. (2021)		✓		✓						
70	Shahrour et al. (2021)	Netherlands	✓		✓						✓
71	Silverio-Fernandez et al. (2019)	Dominican Republic									
72	Srinivasan and Chander (2021)		✓								
73	Stefanic and Stankovski (2019)	Slovenia	✓		✓						

No.	Author	Origin	ST in Construction								
			Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch	Mobile Apps	Building Information Modelling, Virtual Reality, and Augmented Reality	Geofence	Drones/ Unmanned Aerial Vehicles	Wearable Technology/Mobile Sensors	Communication and Video Technology	Robot	Geographic Information Systems
74	Svertoka et al. (2021)		✓								
75	Tokunova and Rajczyk (2020)				✓						
76	W. Fang et al. (2018)	China, UK & Australia									
77	Wang et al. (2020)	Korea	✓	✓				✓	✓		
78	(Getuli et al., 2020)	Italy			✓						
79	Y. Kim et al. (2021)		✓								
80	Yang et al. (2020)	China	✓	✓							
81	Yiu et al. (2018)					✓					
82	Yu et al. (2019)		✓								
83	Zhang et al. (2017)	China	✓		✓						
84	Zhao and Lucas (2015)	United States			✓	✓					
85	Zhou et al. (2018)	China	✓	✓	✓						
86	Zimbelman et al. (2017)	US				✓		✓	✓		
87	Zulu and Muleya (2018)				✓		✓				
	Totals		**54**	**20**	**25**	**8**	**8**	**7**	**12**	**6**	**2**

Source: Authors own work

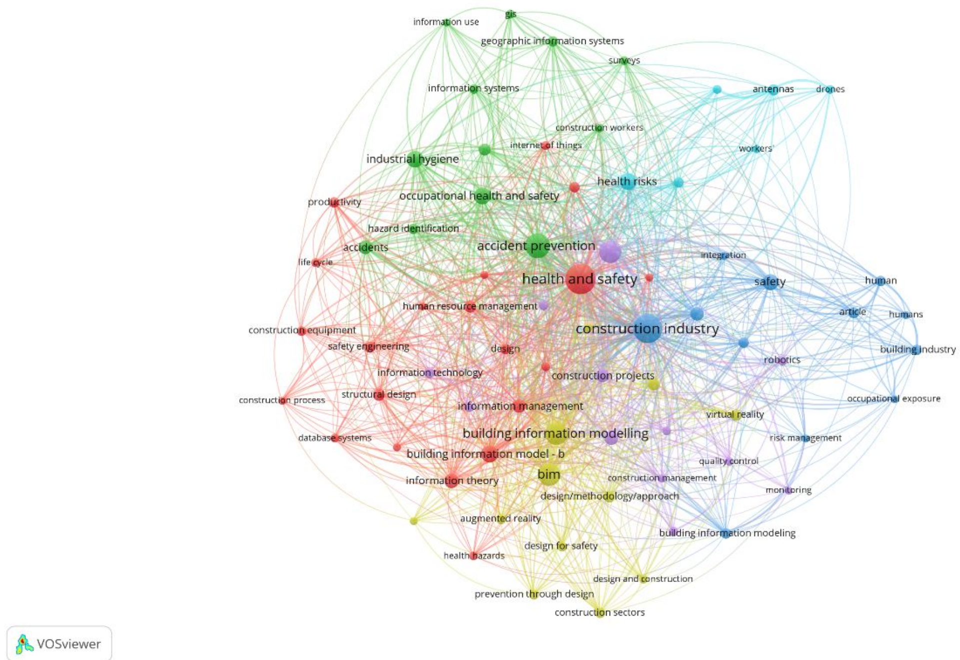

Figure 11: Visualization of keywords occurrence of H&S factors in construction

Source: Authors own work using VOS viewer

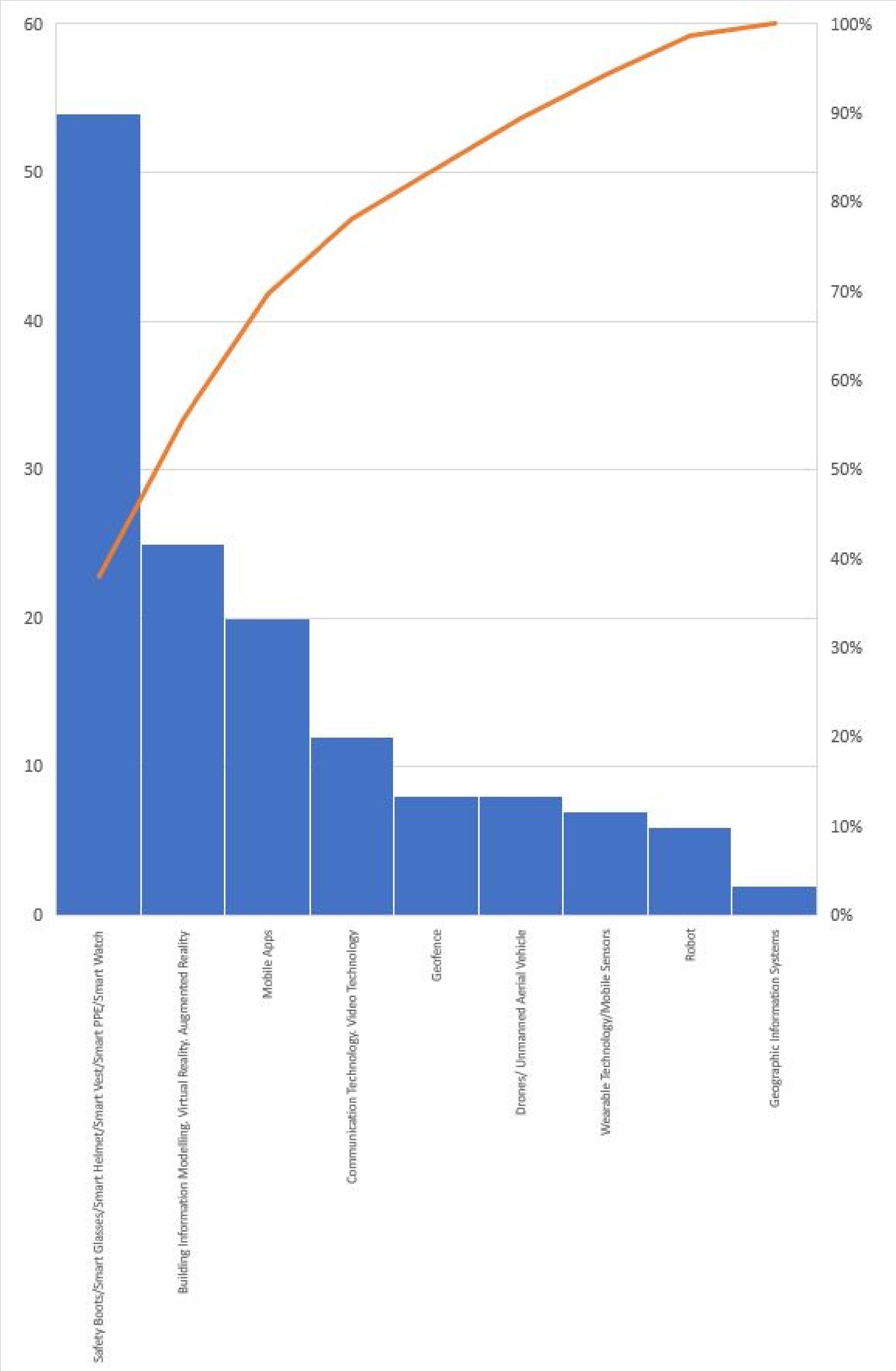

Figure 12: Pareto chart of SMART technology concerning H&S in construction

Source: Authors own work

4. Discussion

A country's economic and social well-being depends critically on H&S. Given that the construction sector touches many lives, it is crucial to talk about how technological advancements have enhanced H&S in the industry and, even better, how they have impacted a wide range of stakeholders. Modest construction projects are prone to overlooking H&S hazards on the worksite. FTS, cuts, burns, scalds, electrocution, and unintentional poisoning are among the several accidents. By following the Extremely Important H&S Rulebook, which includes assessing potential difficulties on compact work sites, employees may avoid regular problems and safeguard the H&S of everybody involved. The broad SLR of more than 232 academic journals and additional reports, legal requirements, and conclusions served as the basis for this discussion. The SLR highlighted health-related concerns or factors that affect construction workers' safety and SMART technology that can be used to reduce risk and enhance workplace safety.

Idoga (2020) stated that the significant factors of construction accidents are widely recognised globally, often called the “Focus or Fatal Four”. It includes falls, falling objects, being trapped between objects and electrocution. This SLR had identified “Focus or Fatal Five”, which combined form 60% of factors identified by various listed authors (refer to Figure 10 and Table 3); it includes:

1. FFH (objects) and trapped between objects
2. FTS
3. Machinery/Equipment Malfunctionand Moving Equipment
4. Pollutants: Chemicals, Airborne Dust, Asbestos
5. Electrocution

Pollutants: Chemicals, Airborne Dust, and Asbestos appeared fourth and above electrocution in the list, which Idoga (2020) had not listed in his “Fatal Four”. The top was FFH, where a falling or projected object struck the worker. The object could be part of the work or equipment, causing it to fall or fly (Idoga, 2020). Similarly, being trapped between objects is when the worker is between a stationary and one in motion (Idoga, 2020). This happens when a building might collapse or be squashed beneath something that has fallen, catching a body part in a machine. Falls often happen from heights on buildings and on industrial and construction sites (Idoga, 2020). It could occur due to faulty scaffolding, an unstable work surface or structural element, unsafe ladders, human error, or the lack of fall protection equipment (Idoga, 2020). ST has been considered to reduce the occurrence of the “Fatal five” in construction and enhance H&S.

Literature research has discovered that modern innovative technologies have integrated well into the construction H&S sectors. Yap, Lee, & Wang (2023) findings revealed that the most effective Smart technologies for construction safety management were wearable technologies, building information modelling, and robotics and automation that are applied to improve hazard identification and enhance safety planning, inspection, monitoring, supervision, and awareness. Six out of 87 Articles on ST in Construction Industries (refer to Table 4) have discussed robots. Robotics are being adopted for sustainable construction (Oke et al., 2024). However, barriers to implementation, such as the fragmented nature of the construction process, resistance by workers and unions, hesitation to adopt innovation, lack of capacity and expertise and lack of support from top-level managers, prevent widespread use (Oke et al., 2024). The barrier clusters include industry, human, economic and technical-related (Oke et al., 2024).

Table 4 shows that the highest factor of the ST is Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch, which 54 Articles out of 87 have considered. Nnaji et al. (2021) found that "These Smart wearables are useful on construction sites for detecting near-miss falls or reducing fall-related injuries, identifying unsafe posture in workers and potential work-related ergonomic risks, monitoring workers' fatigue and workload stress, and other applications." SMART Wearables are available in a wide range of sizes and shapes. Some businesses are quick to jump on board concerning ST, but in the construction industry, the outcome is perceived as slow (Wakefield & Kassem, 2020). For various reasons, many people are hesitant to use wearable technology.

According to Table 4, BIM and mobile apps were in second and third positions, respectively. The BIM technology was discovered to be helpful for danger perception, risk assessment, and spotting safety-related design errors. Additionally, BIM may "integrate data from multiple capture technologies like photogrammetry, GPS, GIS, RFID, augmented reality, virtual reality, laser scanning, and rapid response (QR) coding to provide a variety of detailed data and information about a project, particularly for improving the construction site safety". Furthermore, BIM (Building Information Modelling) is a software that allows for 3D modelling and better collaboration and communication between everyone involved in the project through easy real-time access to updated information. The same can be said for virtual reality and augmented reality modelling, which has been highly praised for allowing workers to interact, look around, and be transported in a virtual environment for their H&S training and learning (Zhao & Lucas, 2015). Besides digital modelling options, drones and geofencing also act as preventative measures for workers, as they can scan and survey building sites and alert them of equipment and machinery locations or possible collisions to guarantee safety and contribute to a safer working environment. Combining various STs used in the construction site may yield better results. The literature review also revealed that Unsafe worksites and practices could be reduced with the help of BIM, Unmanned aerial vehicles (UAVs) and mobile applications.

UAVs have the added benefit of enabling businesses to gather data in circumstances where doing so securely in the past would have been prohibitively challenging or time-consuming, such as conducting surveys in hot climes or inspecting large structures or power lines. Essential advantages include extreme mobility and the ability to take high-quality photographs using drones for less money than with traditional helicopter-assisted photography (Stefanic & Stankovski, 2019). The information gathered by drones can be transformed into volumetric measurements, topographic maps, and 3D structural models to assist architects and builders in planning their projects. As most workers would have access to a mobile device, such as a mobile phone, other technological advances developed to assist with H&S are mobile applications like iAuditor or Safety Meeting, which are safety-focused.

ST may be a source of hazard, too. For example, an uncrewed aerial vehicle (drone) can pose a safety risk. Drones flying away is a common issue. This happens when the wireless Wi-Fi is out of range for the drone, and there is no connection between the drone controller and the aircraft. When this happens, the drone will fly until the battery is depleted and will then make an emergency landing at that position. These landings can be on anywhere. Geofencing is an option to prevent a drone from a flyaway. When geofencing has been set up around the area, the drone will only fly in that area and at a specified height. Another example is SMART PPE. Construction team members must know sufficiently about the PPE's capabilities, how to wear it appropriately, and maintenance advice (Sharma, 2019). The fit should be appropriate for the workers, who must use personal protective equipment. (Sharma, 2019).

Contrary to common assumption, personal protection equipment may raise thermal strain in potentially dangerous workplace conditions, leading to tiredness and decreased productivity; there are many elements to consider when creating protective gear that would provide users with enough protection and comfort (Khlaponin et al., 2020). These include fabric type, the design and care given to textiles, and the construction and fit of clothing (Khlaponin et al., 2020). However, it is advisable to consult the manufacturer's instructions or handbook before beginning a task (Stefanic & Stankovski, 2019). Due to these risks, vision-based non-wearable technologies in H&S are gaining significance as they pose fewer H&S risks created by wearable devices (Purushothaman & Gedara, 2023). Similar technologies, such as AR and VR, are primarily applied to on-site real-time information retrieval and health and safety measures in the construction sector (Oke & Arowoiya, 2022). Seyman Guray and Kismet (2023) state that VR-AR technologies mostly attract the interest of researchers from architectural design studies but lack in construction management. In contrast, Zoleykani et al. (2024) state that virtual reality or extended reality (XR) technologies are the most used XR tools, with most of their applications dedicated to safety training and risk management. Khorrami Shad et al.'s (2024) study results indicate that AR integration with construction effectively mitigates safety concerns.

The following sub-sections discuss the links between "Focus or Fatal Five" and ST.

4.1. Fall from heights

Table 3 reveals that FFH (objects) and trapped between objects is the most dangerous hazard, accounting for 15.47% of the list of collected literature. Fifty-four authors listed it as a critical factor. This substantiates the findings of (Zhang et al., 2015) and (Kim et al., 2020), who provided data on the US and the UK. NZ also had a similar FFH. Figure 2 shows the data on incidents due to FFH between Nov 2019 and Oct 2020 in NZ. Worldwide, these mishaps are categorised under the critical H&S risk. For instance, falls are the second most common reason for accidental mishaps, according to WHO reports from April 2021. Worldwide, 684000 people die from fall-related accidents yearly (Arquillos et al., 2012).

The Fall from Heights factor is one of the most dangerous hazards on site that harms all the stakeholders; at least eleven authors recorded that most construction fatalities occur when people fall from heights. This risk can be minimized by inspecting the site conditions before construction operations using UAV in conjunction with BIM. When properly used, these STs can minimize and will be able to assist in identifying the risk of Falling objects in advance. While wearing hard helmets, employees' heads are shielded from falling objects, projecting objects, electrical contact, UV radiation, weather conditions, and severe temperatures. Workers must wear hard helmets that adhere to AS/NZS 1801:1997 if something is possibly falling from the ceiling (or a comparable standard). Hard helmets are becoming increasingly common on building sites, for example, in NZ, especially where a path of unevenly stained stones or an oily or wet floor could be a potentially hazardous work environment (Ranasinghe et al., 2023).

Srujana (2019) provided a list of safety gear that should be used on the job site. For workers in the construction industry, headgear is worn to protect the head from harm from falling objects; this protective gear is a requirement in the construction industry. Protection for the face and eyes is also a requirement for construction. When invisible objects or dirt flecks get in the eyes, the protective equipment should shield the face, especially the eyes (Srujana, 2019). Additionally, hearing protection is required to protect the ears from loud noises. The use of these hearing aids guards against ear damage.

4.2. Falls, Trips, and slips

In Table 3, FTS are ranked second, with 50 authors listing them as critical factors. Surface contaminants such as water and oil are related to the physical work environment and are common causes of FTS. According to Smith (2024), construction sites are highly susceptible to incidents involving FTS. In 2021, nearly 20% of workplace fatalities occurred in the construction industry, with over a third of these deaths attributed to FTS. The majority of these fatalities were due to people falling from a height in work spots, constituting 46.2% of all fatal FTS accidents that year. Spot-r recognises when a worker trips and falls so that managers are immediately alerted, which is yet to be widely used. A path of unevenly stained stones or an oily or wet floor could be a potentially hazardous work environment and cause FTS (Ranasinghe et al., 2023). With worker push-button warnings and spot-automated fall detection, staff can react to accident occurrences much more quickly, which helps to save critical reaction time (Wakefield & Kassem, 2020). The SMART wearables can also provide data on the area and time of incidents (Wakefield & Kassem, 2020). Knowing when these incidences occur is highly beneficial for investigating accidents and enhancing the general safety culture on the building site (Xu et al., 2022). Awolusi et al. (2018) point out that wearables perform different functions like collecting, storing and receiving information about the workers' biometric signs, location, possible nearby hazards and further work site data. For example, a spot-r or sensor device can be attached to the worker's belt, and it alerts management if they are in a high-risk area or detects falls before they happen.

4.3. Machinery/Equipment Malfunctionand Moving Equipment

Hazards related to Machinery/ Equipment malfunction are the third highest H&S factor, according to Table 3. Smith (2024) examined the fact that accidents occurred despite implementing machine safety measures. After utilising the machine safeguards, they claim that accidents were not avoided since the precautions could not stop all machine actions. According to Lingard, Cooke and Gharaie (2013), backhoes and rollovers were the leading causes of work-related fatalities in the construction industry, and worker contact with heavy machinery and equipment was deemed the scariest incident. Each year, average machine entanglements cause roughly 34,000 industrial injuries (CMA, 2022). Workers in the manufacturing sector sustained about 12 % of the injuries. Most fatalities at work due to machines also come from this sector (about 41 %). Most of the remaining machine-related occupational injuries and fatalities are caused by agricultural, mining, construction, and waste management businesses (CMA, 2022).

Machine Accidents are the most common fatality factor due to the heavy machinery used on site. Machine accidents usually occur when there is a lack of concentration on the operator's side. Machine accidents have a negative impact on the H&S team as well as the operator. People working in the construction industry must wear vibrant colours to indicate the presence of a person at a distance. Reflective clothing is necessary; this clothing is helpful at night or when visibility is reduced. (Srujana, 2019). Workers in the construction industry are more likely to be seen by motorists when they are dressed in high-visibility gear (Edirisinghe, 2019), such as SMART vests. These accidents can be minimized by using SMART sensors for noise monitoring. The audio-based event detection also assists in identifying where this huge machinery works. The SMART cap and SMART watch will positively impact this risk. These SMART wearable technologies will detect if the operator is tired and the operator's well-being whilst operating the machine. SMART vests can aid in emitting an acoustic alarm or sending a signal to the front or rear machines, automatically slowing it down to a manageable speed. Further, Using SMART vests can provide additional benefits and data. For example, Hexoskin SMART Garments features textile sensors to track activity and heart rate monitoring for accurate, real-time monitoring. Customers can access, report, and analyse the data collected from their devices using Hexoskin's Connected Health Platform (Riaz et al., 2014)

4.4. Pollutants

Pollutants or exposure to harmful substances and the environment are the next highest factor in Table 3, with 34 authors referring in their studies. Building site pollution includes asbestos, silica dust, lead paint, solvents, timber preservative chemicals, sediment and run-off. The dangers of exposure to airborne and other contaminants may not be immediately apparent. The leading cause of work-related mortality in NZ now is past asbestos exposure, which is thought to be responsible for 220 deaths annually. Construction sites could present a risk from silica dust (Level.org.nz, 2021). Pollution is present primarily in construction due to chemicals, which can cause Skin diseases. SMART clothing, SMART cap, SMART watches geofencing, and wireless wi-fi could assist the H&S team. These technologies will immediately identify if the worker is in a contaminated area. When exposed, the SMART clothing, a SMART cap and a SMART watch will report the body temperature, the brain condition, and the worker's well-being. These technologies combined can provide the H&S team with an idea of the employee's condition. The Slip and trip factor harms all the stakeholders as this is one of the most common hazards on a construction site, with the SMART helmet, SMART gloves, SMART boots, spot-r clips, the building information modelling and the UAV (Márquez-Sánchez et al., 2021). This risk can be recorded and analysed to minimise the hazard's impact. Workers who wear foot protection are less likely to trip or slip. Employees' use of non-work shoes must be avoided since it increases the risk to their safety (Srujana, 2019). This factor might even be removed with the assistance of Building Information Modelling technology. Eight of the authors mentioned that these STs would positively impact this risk.

4.5. Electrocution

One of three ways can result in electrocution: Ionization, known as arc flash, occurs when electricity is transmitted through two conducting metals. Arc blast: During an arc flash, a fault current causes some pressure wave components (Idoga, 2020). This quick increase in the mixture of vaporisation and air exacerbated by conducting materials causes the pressure to weave components known as an arc blast (Idoga, 2020). Electrical shock has caused many construction-related injuries and even fatalities (Idoga, 2020). Employees have a high workload, from working around the clock to completing projects on time, fulfilling corporate goals, and supporting the company's general mission (Ranasinghe et al., 2023). This necessitates speeding up work and practising shortcuts, leading to H&S issues (Ranasinghe et al., 2023). Electrocutions occur when construction companies use undeveloped and under-protected electrical sources on site. These temporary electrical installations need to be checked daily and serviced regularly. Safety gloves are essential tools every construction worker should have (Sharma, 2019); specific gloves must be utilized when working with electricity. Though SMART technology cannot prevent electrocution, SMART shirts, SMART clothing, and SMART watches will assist the H&S team with determining the workers' condition after electrocution. SMART shirts will monitor heart rate, SMART clothing will control body temperature, and the SMART watch will report on the worker's well-being. However, SMART wearable technology that can still prevent electrocution is yet to be commercialized. To prevent electrocution, SMART PPE (Personal Protection Equipment) wearables catered specifically for hazardous electrical sites can protect workers from electrocution or electric shock (Srujana, 2019). Aside from electrocution, SMART PPE can also be used when working with toxic substances (Sharma, 2019). Specific body sensors have also been utilised to detect and mitigate bodily injuries due to the labour intensity of a construction worker.

4.6. ST interactions

54 out of 87 authors advocated Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch use in Construction H&S. 20 authors connected Mobile Apps to Construction H&S. Building Information Modelling, Virtual Reality and Augmented Reality were connected to Construction H&S by 25 authors. Eight authors connected Geofence, Drones/ Unmanned Aerial Vehicles. Similarly, Wearable Technology/Mobile Sensors were connected by eight. Eight authors focused on communication and Video Technology, while 6 discussed the Robot's part in the Construction of H&S. 2 authors linked Geographic Information Systems to the Construction of H&S.The SLR revealed that the ST used as a standalone is less effective and often works in conjunction with others. SL analysis revealed the ST currently used, its interrelations and its connectivity to H&S (refer to Figure 13).

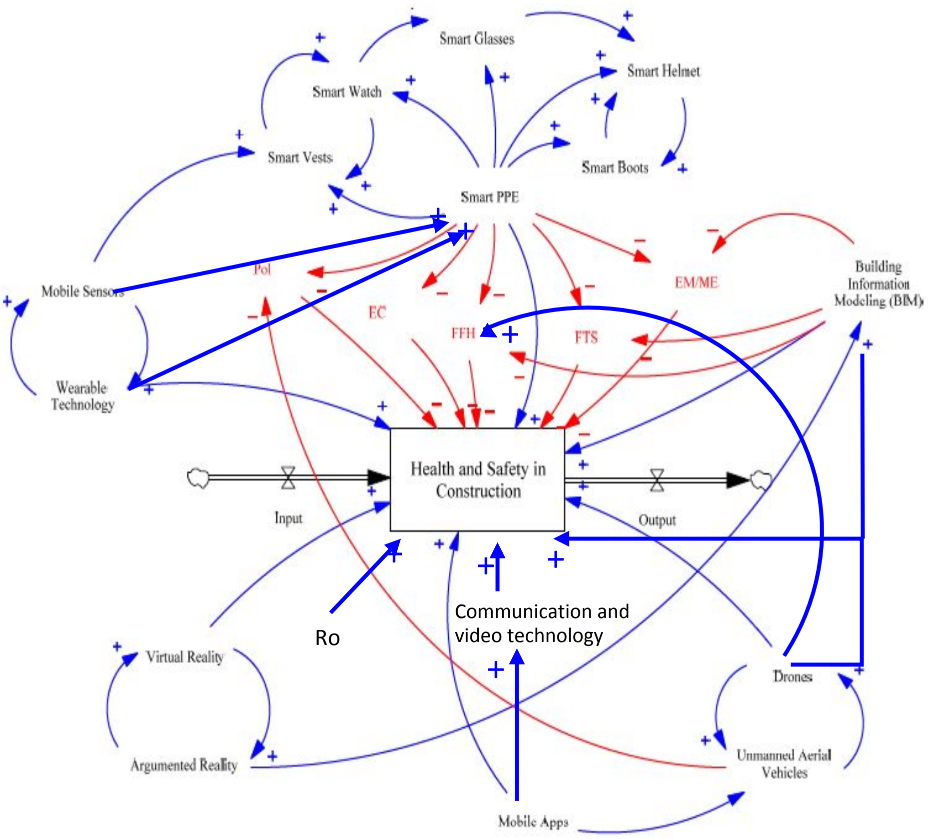

Figure 13 Interactions of factors affecting H&S and ST (Source: Authors own work using Vensim software)

Safety Boots, SMART Glasses, SMART Helmet, SMART Vest, SMART PPE, and SMART Watch were interconnected and connected to SMART PPE (Abainza et al., 2020; Dogbe et al.,2020). Many authors state they are used in conjunction (Y. Kim et al.,2021), Yang et al.,2020). SMART PPE is connected to mobile apps, which play a crucial role in integrating and managing data from various safety technologies (Guo & Li,2021), and mobile apps are connected to communication and video technology (Ahmed,2019). Mobile sensors and venerable technology are interconnected (Nath et al., 2017; Wang et al., 2020) and are a reinforcing loop. Mobile sensors and wearable technology work together to improve each other's reliability (Ammad et al., 2021; Wang et al.,2020). Mobile Apps are connected to drones and uncrewed aerial vehicles (Maali et al., 2024), and drones and uncrewed aerial vehicles form a reinforcing loop. Building Information Modelling, Virtual Reality, and Augmented Reality are interconnected (Maali et al., 2024); Virtual Reality and Augmented Reality form a reinforcing loop. Reinforcing loops represent factors supplementing each other. Similarly, BIM, UAVs, and drones work together to improve H&S. UAVs and drones are aided by mobile applications to improve their effectiveness (Zulu & Muleya, 2018). BIM also combines with virtual and augmented reality to produce the best results. However, the literature review also revealed that ST is not available commonly for the following (which combinedly form around 40 % of factors referred by authors:

- Adverse Weather Conditions
- Vibrations
- Violence
- Legislative
- Financial
- Social
- Cultural Training Communication
- Disease and illness

- Fire and Explosion
- Over Exertion
- Suicide
- Physiological factor

Legislative, Financial, Social, Suicide, and Physiological factors may be out of reach of ST at present due to its complexity, expertise and influence on construction professionals. However, adverse Weather Conditions, Vibrations, Violence, Disease and illness, Fire and Explosion, and Over Exertion can be specifically targeted for future SMART technology research. SLR reveals that current digital developments profoundly help improve H&S within construction. It has revolutionised every aspect of the construction business, and with the continued advancement of technology, the future looks promising. The stakeholder group that benefits directly from these improvements are the employees. Due to their direct involvement as workers, they would be of utmost priority. Evidence has suggested that long-term employee benefits are happiness and a morale boost (WORKSAFE, 2021). When H&S measures are not in place to protect the workers, the business is accountable under the law and could face heavy fines. This would have a domino effect on the business's operations, which could cause it to be deregistered and unable to be productive and make a profit. A business's costs are much higher when H&S measures are neglected. Also, the complexity of a construction business involves more than the business itself, as a project can draw in third parties like contractors, subcontractors, suppliers and professionals like architects, engineers, project managers, quantity surveyors and the like, and they will be at the site at some stage of the project. Their work will also be made more accessible and more efficient with the help of technology. However, when those directly involved with the project are not protected, the risks and harm are much more significant.

Clients or investors are the next groups affected by the improved technology. As projects require much capital to commence, investors rely on the investment to fruition; thus, they place a tremendous amount of trust in the business they have contracted to carry out the work. However, as stated earlier, if parties directly affected by the work are in danger or harmed, the work will not be delivered. The technology not only supports their H&S but also allows clients or investors to keep track of the project's progress in real-time, as well as the ability to make changes or improvements. For instance, drones can monitor construction sites for potential hazards, and virtual reality can be used for safety training. Society is the final group to benefit from using technology as an H&S measure within construction. They will be economically advantageous as a substantial correlation exists between our country's overall productivity and GDP. Setting a high standard for H&S in construction is not only expected by law but also a social responsibility, and businesses must show the public that they care and prioritise the H&S of people first, and only then can profit follow suit.

SMART technology incorporated into the construction industry depends on various factors, such as the trust between construction professionals and technological developers, which helps the transition to adoption. Another factor is the technical advancement factors, where all the stakeholders should be willing to embrace changes as more advanced ST would be innovated over time. Though there could be a willingness to adopt technology into the construction industry, its sustainability will be crucial among the various stakeholders. These factors lead to the challenges of adopting SMART technology into the construction industry, including but not limited to the high initial investment, the need for retraining and upskilling of the workforce, and the potential resistance to change. Apart from the construction professionals, the other key stakeholders (taxpayers and the government) who fund and care for the H&S aftereffects need to be involved in adopting SMART technology into the construction industry. The privacy security and risks involved in using SMART technology in the construction industry affect not only organizations and the government but also the well-being, quality of life and regulations concerning the citizens. Therefore, to have functional SMART technology offering services in the construction industry, there is a need to set standards and protocols to check the quality and adherence to set rules, and by doing so, the mobility of the SMART technology will be enhanced.

5. Conclusion

A country's economic and social well-being relies heavily on health and safety (H&S) in the construction sector, affecting many stakeholders. This review article examines the factors that impact H&S and the use of SMART Technologies (SM) to mitigate risks in the industry. The selected papers highlight the need for intelligent technologies to minimize injuries, illnesses, and severe harm in construction and encourage readers to consider their implementation. One hundred forty-five journal articles for H&S factors and 87 ST journal articles were discussed in this SLR (refer to Table 3 and Table 4). Five major databases, Google Scholar, Scopus, Science Direct, and Emerald Insight, were used to search and extract the crucial article list. This review article highlighted the factors affecting H&S (H&S) and the ST (SM) used to mitigate them in the Construction Industry to encourage readers and potential construction audiences to consider the need for intelligent technologies to minimise the risks of injuries, illnesses, and severe harm in the construction industry. The SLR critically identified “fatal or focus five” factors (FFH/objects and trapped between objects; FTS; Machinery/Equipment Malfunction and Moving Equipment; Pollutants: Chemicals, Airborne Dust, Asbestos; and Electrocution) that for 60% of factors search. The ST includes Safety Boots/SMART Glasses/SMART Helmet/SMART Vests/SMART PPE/SMART Watch, Mobile Apps, Building Information Modelling (BIM), Virtual Reality/Augmented Reality, Drones/ Unmanned Aerial Vehicles, and Wearable Technology/Mobile Sensors were identified as tools that mitigate the risk posed by “Fatal five”.

Further, the SLR highlighted that other factors within the scope of ST, such as Weather Conditions, Vibrations, Violence, Disease and illness, Fire and Explosion, and Over Exertion, are yet to be adopted in the field. The paper's originality is that it is the first to highlight all factors affecting H&S and ST interactions that help mitigate associated risks and identify the critical “Fatal five” factors; further, it identified factors within the ST scope that are yet to be explored.

5.1. Limitations

SLR methodology limitations of not obtaining the most updated field knowledge are critical and are offset by choosing 72% of H&S and 92% of SM review literature post-2017. Limitations to capturing articles because of the restriction of database access: only English language search and journals that are not a part of the databases selected are acknowledged. However, key database search that recognises rigorous peer-reviewed articles offset these limitations. The researcher's Bias is acknowledged.

5.2. Practical and Theoretical Implications

This article highlights the construction of H&S factors and their interlinks with ST that aid in mitigating associated risks. The article establishes the Fatal five and trivial 15 factors, which would help construction managers prioritise H&S risks. Further, the connectivity of ST discussed would aid the organisation's overall H&S management. The practical and theoretical implications contain an improved understanding of all factors affecting H&S and ST that are accessible to help mitigate risks. The tactical managers could use the ST to decrease H&S risks during construction. This article on H&S and ST and relationships can theorize that the construction industry is more likely to identify clear root causes of H&S and related ST than previously. Practical implications are high, as using such SMART technologies would improve the economic consequences through injury prevention, increasing productivity, and cost reduction. The theoretical implications include a greater understanding for academics on H&S factors, ST and gaps in ST concerning H&S, which can be expanded to provide new insights into existing knowledge.

5.3. Future Research

This SLR reveals a lack of knowledge and commercialisation of ST, specifically for adverse Weather Conditions, Vibrations, Violence, Disease and illness, Fire and Explosion, and Exertion. These could be the basis and direction for future research in ST. This paper provides theoretical insights and additional empirical work to complement them, which could be potential future research. The paper identified "Fatal five" risks and SMART technology adoption gaps. However, future research with real-world data to support the argument will strengthen and add to the knowledge.

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SMART Technologies that Influence Construction Health & Safety Factors Risk Reduction in The Current Digital Era

Table 1 Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Construction: Discipline: Engineering, Subdiscipline: Building Construction	Not in Construction
H&S in construction	Not in H&S
Risk, accident, or injury in construction	Not related to risk, accident, or injury in construction
Prevention of risk, accident, or injury in construction	Not related to the prevention of risk, accident, or injury in construction
ST in Construction H&S	Not related to ST in Construction H&S
ST in the prevention of H&S Risk, accident, or injury	Not related to ST in the prevention of H&S Risk, accident, or injury
Written in English	Written in languages other than English
Major databases	Small databases
Academic articles	Websites and pages

Source: Authors own work

Table 2: Literature search results

	Selection Criteria	
Databases	**Without filters**	**Discipline: Engineering Subdiscipline: Building Construction Year: from 2012**
Keyword Combination 1	**TITLE-ABS-KEY ("construction" AND "H&S" OR "H&S" AND "risk" OR "accident" OR "injury")**	
Scopus	271	148
Emerald Insight	1743	58
ScienceDirect	443	31
Google Scholar	1450	94
Keyword Combination 2	**TITLE-ABS-KEY ("construction" AND "H&S" OR "H&S" AND "risk" OR "accident" OR "injury" AND "prevention" AND "SMART technology")**	
Scopus	134	16
Emerald Insight	255	34
ScienceDirect	365	30
Google Scholar	585	65

Source: Authors own work

Table 3: Factors affecting H&S in the construction industry

Item	Author	Origin	Year	Factors affecting H&S in the construction industry																			
				Physiological and psychological factor	Falls, Trips, and slips	Fall from heights/objects, trapped between objects	Electrocution	Machinery/Equipment Malfunction. Moving Equipment	Pollutants. Chemicals, Airborne Dust, Asbestos	Unsafe worksite	Adverse Weather Conditions	Vibrations	Violence	Legislative	Financial	Social	Cultural	Training	Communication	Disease and illness	Fire and Explosion	Over Exertion	Suicide
1	(Abas & Blismas, 2021)	Malaysia	2021		✓	✓	✓	✓	✓	✓		✓									✓		
2	(Abas et al., 2020)	Malaysia	2020	✓	✓	✓	✓	✓	✓	✓	✓												
3	(Abas et al., 2021)		2020						✓		✓							✓					
4	(Asilian-Mahabadi et al., 2020)	Iran	2020							✓													
5	(Agbolosu–Amison & Acheampong, 2021)	Ghana	2021		✓																		
6	(Agyekum et al., 2018)	Ghana	2018							✓													
7	(Ahmed, 2019)	Bangladesh	2019					✓		✓												✓	
8	(Asanka & Ranasinghe, 2015)	Sri Lanka	2015			✓					✓								✓			✓	
9	(Ashuro et al., 2021)	Ethiopia	2021		✓																		
10	(Atique et al., 2012)	Qatar	2012			✓																	
11	(Awolusi et al., 2018)	USA	2018	✓	✓	✓	✓	✓	✓	✓	✓												
12	(B. Choi et al., 2019)	Netherlands	2019	✓																			
13	(B. G. Kang et al., 2017)	USA	2017			✓	✓												✓				
14	(Bangaru et al., 2020)	Switzerland	2020	✓																			
15	(Newaz et al., 2022)	Australia	2022		✓	✓																	
16	(Betit et al., 2017)	USA	2017																				
17	(Birabakaran & Nagapan, 2021)	Malaysia	2021					✓															
18	(Brolin et al., 2021)	Sweden/Germany	2021		✓																		
19	(Brum, 2020)	Malaysia	2020	✓				✓					✓					✓					
20	(Sacks et al., 2013)	U.S	2013							✓													
21	(Vincoli, 2024)	Canada	2024			✓	✓		✓												✓	✓	
22	(Carabott, 2015)	Not mentioned	2015											✓			✓	✓					
23	(Carrillo-Castrillo et al., 2017)	Spain	2016		✓																		
24	(Chawdhry et al., 2021)	Bangladesh	2021		✓	✓	✓	✓	✓	✓		✓									✓	✓	
25	(Hwang et al., 2017)	Singapore	2017	✓	✓	✓	✓	✓	✓	✓													
26	(Chen & Demachi, 2021)	Not mentioned	2021			✓																	
27	(Nadhim et al., 2016)	Australia	2016			✓																	
28	(Peng et al., 2014)	Taiwan	2014			✓																	
29	(Zhao et al., 2016)	Taiwan	2016				✓				✓											✓	
30	(Chi et al., 2012)	Taiwan	2021				✓	✓															
31	(Cho et al., 2018)	USA	2018			✓																	
32	(Choi & Carlson, 2014)	USA	2014	✓	✓			✓		✓													
33	(Collins & Spillane, 2020)	UK	2020						✓														
34	(Durdyev et al., 2017)	Cambodia	2017		✓	✓																	
35	(Williams et al., 2019)	Nigeria	2019					✓					✓										

Item	Author	Origin	Year	Factors affecting H&S in the construction industry																			
				Physiological and psychological factor	Falls, Trips, and slips	Fall from heights/objects, trapped between objects	Electrocution	Machinery/Equipment Malfunction. Moving Equipment	Pollutants. Chemicals, Airborne Dust, Asbestos	Unsafe worksite	Adverse Weather Conditions	Vibrations	Violence	Legislative	Financial	Social	Cultural	Training	Communication	Disease and illness	Fire and Explosion	Over Exertion	Suicide
36	(Eskandar et al., 2019)	Not mentioned	2019	✓	✓	✓			✓		✓					✓							
37	(W. Fang et al., 2018)	China	2018			✓																	
38	(Murray et al., 2013)	U.S	2013		✓	✓	✓	✓	✓			✓									✓		
39	(Brauer, 2022)	U.S	2022		✓	✓	✓	✓	✓	✓		✓									✓		
40	Gelmini et al. (2020)	U.S	2020			✓																	
41	(Jaafar et al., 2018)	Malaysia	2018			✓	✓														✓	✓	
42	Ghimire and Neupane (2020)	UK	2020																	✓			
43	(Allen & Iano, 2019)	U.S	2019								✓												
44	Giri (2020)	India	2020					✓	✓	✓													
45	Glass et al. (2017)	NZ	2017						✓														
46	Goh et al. (2016)	Malaysia	2016			✓					✓												
47	Guo et al. (2019)	Not mentioned	2019	✓					✓														
48	(Abu Aisheh et al., 2022)	Malaysia	2022			✓					✓												
49	Hamid et al. (2019)	Malaysia	2019		✓																		
50	Han et al. (2013)	Malaysia	2021			✓																	
51	Hashem et al. (2013)	Libya	2013	✓	✓	✓									✓			✓					
52	(Guo et al., 2016)	USA	2016	✓	✓	✓	✓	✓	✓	✓		✓											
53	Hemler et al. (2020)	USA	2020		✓																		
54	Hoła et al. (2017)	Poland	2017							✓													
55	Hosseini et al. (2020)	Iran	2021				✓																
56	Howard (2017)	USA	2017					✓															
57	Ichikawa (2018)	Japan	2018				✓																
58	Idoga (2020)	Nigeria	2020		✓	✓	✓																
59	(Ijaola et al., 2021)	Nigeria	2021		✓	✓	✓	✓	✓	✓											✓	✓	
60	Ismail and Ghani (2012)	Malaysia	2012		✓	✓	✓	✓															
61	(Woźniak & Hoła, 2024)	Poland	2024			✓	✓																
62	Kambadur (2020)	NZ	2020		✓	✓				✓													
63	Kambadur (2020)	India	2015		✓		✓	✓		✓													
64	Kang and Ryu (2019)	Korea	2019			✓																	
65	Kantova (2017)	Czech Republic	2017										✓										
66	Kaur et al. (2021)	USA	2021																				
67	Kazar and Comu (2020)	Turkey	2020																			✓	
68	Khan et al. (2019)	Pakistan	2019		✓		✓																
69	Kim et al. (2018)	Korea	2018					✓													✓		
70	J. H. Kim et al. (2021)	Switzerland	2021		✓			✓															
71	Kim et al. (2022)	UK	2021	✓																			
72	Kurien et al. (2018)	Netherlands	2018	✓	✓			✓			✓												
73	Kuta et al. (2021)	USA	2021	✓																			
74	Lai et al. (2019)	UK, China, Hong Kong	2019																				

Item	Author	Origin	Year	Factors affecting H&S in the construction industry																			
				Physiological and psychological factor	Falls, Trips, and slips	Fall from heights/objects, trapped between objects	Electrocution	Machinery/Equipment Malfunction. Moving Equipment	Pollutants. Chemicals, Airborne Dust, Asbestos	Unsafe worksite	Adverse Weather Conditions	Vibrations	Violence	Legislative	Financial	Social	Cultural	Training	Communication	Disease and illness	Fire and Explosion	Over Exertion	Suicide
75	Lamm et al. (2017)	NZ	2017		✓	✓				✓													
76	(Fang et al., 2015)	UK	2015																			✓	
77	Lee et al. (2019)	Korea	2019					✓															
78	Lee et al. (2020)	U.S	2018			✓		✓	✓	✓		✓											
79	Leon-Kabamba et al. (2018)	Singapore	2018																	✓			
80	Lette et al. (2018)	Ethiopia	2018		✓																		
81	Li et al. (2019)	China	2019					✓															
82	Li et al. (2021)	Not mentioned	2020						✓														
83	Lingard et al. (2017)	UK	2017																	✓			
84	Liu et al. (2019)	NZ	2019	✓	✓	✓	✓	✓	✓	✓													
85	Martin et al. (2021)	Trinidad	2021																				
86	Martinez et al. (2020)	Chile	2020					✓															
87	McGuinness et al. (2019)	U.S	2019		✓	✓	✓																
88	Milner et al. (2019)	Australia	2019																				✓
89	Mizzi (2019)	UK	2019						✓														
90	Moda et al. (2019)	Nigeria	2018						✓														
91	(Kalteh et al., 2021)	Iran	2021										✓									✓	
92	Mohammadi et al. (2018a)	Iran	2018								✓											✓	
93	Mohd Amir Shazwan and Ee (2018)	Malaysia	2018																				
94	Morrissey et al. (2021)	Not mentioned	2021								✓									✓			
95	Moshashaei et al. (2017)	Norway	2017					✓													✓		
96	Mostly (2022)	Saudia Arabia	2019																				
97	Nadhin et al. (2016)	Switzerland	2016		✓	✓					✓												
98	Namian et al. (2021)	U.S	2021			✓		✓															
99	Nath et al. (2017)	Netherlands	2017	✓					✓														
100	(Zhang et al., 2015)	U.S	2015		✓			✓		✓												✓	
101	Osei-Asibey et al. (2021)	Ghana	2021								✓								✓			✓	
102	Panuwatwanich et al. (2020)	Thailand	2020			✓																	
103	Park et al. (2020)	South Korea	2020				✓				✓											✓	
104	Patel et al. (2021)	U.S	2018					✓															
105	Pedley (2021)	Not mentioned	2021		✓																		
106	(Tadesse & Israel, 2016)	Israel	2016			✓																	
107	Rafindadi et al. (2022)	Malaysian	2020			✓		✓															
108	Rameezdeen and Elmualim (2017)	Australia	2017																			✓	
109	Robert et al. (2018)	U.S	2018					✓					✓										
110	S. D. Choi et al. (2019)	USA/South Korea/China	2019		✓	✓																	
111	(Ramkalawon Veerapen Chetty et al., 2024)	Mauritius	2024		✓	✓	✓	✓	✓	✓		✓									✓	✓	

Item	Author	Origin	Year	Factors affecting H&S in the construction industry																			
				Physiological and psychological factor	Falls, Trips, and slips	Fall from heights/objects, trapped between objects	Electrocution	Machinery/Equipment Malfunction. Moving Equipment	Pollutants. Chemicals, Airborne Dust, Asbestos	Unsafe worksite	Adverse Weather Conditions	Vibrations	Violence	Legislative	Financial	Social	Cultural	Training	Communication	Disease and illness	Fire and Explosion	Over Exertion	Suicide
112	SAMUEL (2019)	Malaysia	2017		✓		✓																
113	Sanni-Anibire et al. (2020)	Saudi Arabia	2019		✓																		
114	(Sacks et al., 2013)	UK	2013								✓											✓	
115	Sazonova et al. (2018)	Russia	2018						✓														
116	Sehsah et al. (2020)	Egypt	2020			✓		✓															
117	Shafique and Rafiq (2019)	Hong Kong	2019		✓																		
118	Shiau et al. (2020)	China	2020				✓																
119	Smith et al. (2014)	USA	2014		✓																		
120	Szóstak et al. (2021)	Poland	2021			✓																	
121	Tamburrini et al. (2020)	India	2020						✓														
122	(Thomas & Sudhakumar, 2014)	India	2014						✓														
123	(Tran et al., 2021)	Korea	2020							✓											✓		
124	Tunji-Olayeni et al. (2018)	Nigeria	2018		✓	✓			✓				✓										
125	Umar and Egbu (2018)	Oman	2018																			✓	
126	Valero et al. (2017)	Netherlands	2020	✓																			
127	Vitharana et al. (2015)	Sri Lanka	2015	✓	✓	✓	✓	✓	✓	✓		✓											
128	Walters and Quinlan (2019)	UK	2018						✓														
129	Williams et al. (2018)	Malaysia	2018		✓				✓														
130	Williams et al. (2019)	Nigeria	2019		✓																		
131	Winge et al. (2019)	Norway	2018			✓	✓	✓															
132	Xiao et al. (2016)	China	2016										✓										
133	Xiong et al. (2019)	China	2019		✓	✓		✓					✓								✓	✓	
134	Xu and Xu (2021)	China	2021			✓																	
135	Y. Kang et al. (2017)	USA	2017		✓	✓	✓	✓															
136	Yan et al. (2018)	Netherlands	2018	✓																			
137	Yang et al. (2016)	Netherlands	2016		✓																		
138	Yang et al. (2017)	U.S	2017		✓	✓		✓														✓	
139	Yang et al. (2020)	USA	2020																		✓		
140	Yang et al. (2021)	China	2021										✓										
141	Yap and Lee (2020)	Malaysia	2020	✓	✓	✓	✓	✓	✓	✓													
142	Yi (2020)	Korea	2020																		✓		
143	Yoon et al. (2013)	Taiwan	2013	✓				✓	✓		✓								✓				
144	Zhao et al. (2015)	U.S	2015	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										
145	Zuo et al. (2017)	Australia	2017						✓														
Totals				**22**	**50**	**54**	**32**	**43**	**34**	**26**	**18**	**9**	**10**	**1**	**1**	**1**	**1**	**4**	**4**	**4**	**14**	**20**	**1**

Source: Authors own work

Table 4: ST in the Construction Industry

No.	Author	Origin	ST in Construction								
			Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch	Mobile Apps	Building Information Modelling, Virtual Reality, and Augmented Reality	Geofence	Drones/ Unmanned Aerial Vehicles	Wearable Technology/Mobile Sensors	Communication and Video Technology	Robot	Geographic Information Systems
1	Abainza et al. (2020)	Philippines	✓	✓				✓	✓		
2	Adjiski et al. (2019)	Macedonia	✓								
3	Ahmed (2019)	Banglades h		✓		✓			✓		
4	Ahn et al. (2019)	United States	✓								
5	Akinosho et al. (2020)	Netherland			✓		✓			✓	
6	Alizadehsalehi et al. (2020)				✓		✓				
7	Ammad et al. (2021)	Malaysia	✓	✓				✓	✓		
8	Anast et al. (2021)					✓					
9	Antwi-Afari et al. (2019)	Hong Kong	✓								
10	Ashour et al. (2016)	UAE	✓				✓			✓	
11	Ashtekar et al. (2019)		✓								
12	Awolusi et al. (2018)	USA	✓	✓							
13	Azzazy et al. (2021)	NZ	✓								
14	B. Hwang and S. H. Lee (2017)	Netherland s	✓								
15	Baek and Choi (2020)	Korea		✓							
16	Banerjee and Nayak (2021)	Not mentioned		✓	✓						
17	Bangaru et al. (2020)	USA									
18	Barata and da Cunha (2019)	Portugal	✓								
19	Bolshakova et al. (2018)				✓						
20	Callejas Sandoval and Kwon (2019)	USA	✓								
21	Camero-Jurado et al. (2020)	Switzerlan d	✓								
22	Chan et al. (2020)		✓								
23	Cheng et al. (2019)								✓		
24	Choi et al. (2017)	USA	✓	✓				✓	✓		

No.	Author	Origin	ST in Construction								
			Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch	Mobile Apps	Building Information Modelling, Virtual Reality, and Augmented Reality	Geofence	Drones/ Unmanned Aerial Vehicles	Wearable Technology/Mobile Sensors	Communication and Video Technology	Robot	Geographic Information Systems
25	Ciampa et al. (2018)	Italy					✓				
26	Dogbe et al. (2020)	USA	✓	✓							
27	Edirisinghe (2019)	Australia			✓						
28	Fargnoli and Lombardi (2020)		✓		✓						
29	Ganah and John (2015)	UK		✓	✓				✓		
30	Getuli et al. (2018)	Italy			✓						
31	Gheisari and Esmaeili (2016)	U.S	✓								
32	Guo and Li (2021)	China	✓	✓							
33	Haq (2020)	Australia	✓			✓					
34	Haupt et al. (2019)	Not mentioned	✓	✓	✓					✓	
35	Howard (2017)						✓				
36	Jayasree and Kumari (2020)	India	✓								
37	Jiang et al. (2021)	Netherland					✓			✓	
38	Jiang et al. (2021)				✓						
39	Johansson et al. (2019)		✓								
40	Kang and Ryu (2019)	USA								✓	
41	Kim et al. (2018)	Switzerland	✓								
42	Lee et al. (2020)								✓		
43	Li (2017)	Hong Kong									✓
44	Liu et al. (2019)	NZ		✓					✓		
45	Liu et al. (2021)	USA								✓	
46	Luo et al. (2020)	China	✓	✓							
47	Manzoor et al. (2021)				✓						
48	Marefat et al. (2018)	USA	✓		✓						
49	Márquez-Sánchez et al. (2021)	Switzerland	✓								
50	Martin and Voix (2017)		✓								
51	Mehata et al. (2019)	India	✓								

No.	Author	Origin	ST in Construction								
			Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch	Mobile Apps	Building Information Modelling, Virtual Reality, and Augmented Reality	Geofence	Drones/ Unmanned Aerial Vehicles	Wearable Technology/Mobile Sensors	Communication and Video Technology	Robot	Geographic Information Systems
52	Mordue and Finch (2019)				✓						
53	(Motawa & Kardakou, 2018)				✓		✓				
54	Nath et al. (2017)	USA	✓	✓				✓	✓		
55	Niu et al. (2016)	USA	✓	✓							
56	Nnaji et al. (2021)	Switzerlan d	✓								
57	Park et al. (2017)	USA	✓	✓							
58	Parn et al. (2019)	UK	✓								
59	(Podgorski et al., 2017)	Poland	✓								
60	Q. Fang et al. (2018)		✓								
61	Rajendran et al. (2020)	Netherland s	✓								
62	Rey-Mercvhan et al. (2021)	Switzerlan d	✓								
63	(Maali et al., 2024)	USA	✓	✓	✓	✓		✓	✓		
64	Riaz et al. (2014)	Australia			✓						
65	Robert et al. (2016)	USA	✓								
66	Roofigari-Esfahan et al. (2021)		✓								
67	S. Hwang and S. Lee (2017)	United States	✓								
68	Sanchez et al. (2021)	SPAIN	✓			✓					
69	Shafiq et al. (2021)		✓		✓						
70	Shahrour et al. (2021)	Netherland s	✓		✓						✓
71	Silverio-Fernandez et al. (2019)	Dominican Republic									
72	Srinivasan and Chander (2021)		✓								
73	Stefanic and Stankovski (2019)	Slovenia	✓		✓						
74	Svertoka et al. (2021)		✓								
75	Tokunova and Rajczyk (2020)				✓						

No.	Author	Origin	ST in Construction								
			Safety Boots/SMART Glasses/SMART Helmet/SMART Vest/SMART PPE/SMART Watch	Mobile Apps	Building Information Modelling, Virtual Reality, and Augmented Reality	Geofence	Drones/ Unmanned Aerial Vehicles	Wearable Technology/Mobile Sensors	Communication and Video Technology	Robot	Geographic Information Systems
76	W. Fang et al. (2018)	China, UK & Australia									
77	Wang et al. (2020)	Korea	✓	✓				✓	✓		
78	(Getuli et al., 2020)	Italy			✓						
79	Y. Kim et al. (2021)		✓								
80	Yang et al. (2020)	China	✓	✓							
81	Yiu et al. (2018)					✓					
82	Yu et al. (2019)		✓								
83	Zhang et al. (2017)	China	✓		✓						
84	Zhao and Lucas (2015)	United States			✓	✓					
85	Zhou et al. (2018)	China	✓	✓	✓						
86	Zimbelman et al. (2017)	US				✓		✓	✓		
87	Zulu and Muleya (2018)				✓		✓				
	Totals		**54**	**20**	**25**	**8**	**8**	**7**	**12**	**6**	**2**

Source: Authors own work

Author Response.

We carefully addressed all the comments from reviewers and editors, and we thank the editor, regional editor, and reviewers for their input.

Reviewer(s)' and Regional Associate Editor Comments to Author:

Reviewer: 1

Recommendation: Minor Revision

Comments:
The overall paper is impressive. The extensive review of relevant literature is commendable and well-analysed. I am pleased to receive the revised version, which reflects several of my suggestions. The revisions have significantly improved the manuscript, and the recommended changes have been effectively implemented. While the language is now clearer and more concise, there are still a few minor points that could be further refined to enhance the paper's quality. Specifically, regarding the tables and figures: For Figure 8, could the author clarify if this was generated using VOS Viewer? Additionally, Figure 12 includes the label "chart title"—it would be better to either remove this, as it is already mentioned at the bottom of the figure or replace it with the actual chart title for consistency throughout the paper.

Author Comment: Thank you for your keen observation and eye for detail; we have removed the chart titles from the figures (the track changes are not showing this due to word functionality). Figure 8 was not from the VOS viewer; the same has been corrected.

Additional Questions:
1. Originality: Does the paper contain new and significant information adequate to justify publication?: Yes

Author Comment: Thank you

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: Yes

Author Comment: Thank you

3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts, or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: Yes

Author Comment: Thank you

4. Results: Are results presented clearly and analysed appropriately? Do the

conclusions adequately tie together the other elements of the paper?: Yes - Thank you for incorporating my comments and suggestions.

Author Comment: Thank you

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: Yes

Author Comment: Thank you

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the field and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: Yes - Thank you for incorporating my comments and suggestions. The Manuscript has improved significantly in terms of clarity and flow.

Author Comment: Thank you

Reviewer: 2

Recommendation: Accept

Comments:
the revisions meet most of the review criteria, and overall, the authors' commitment to improving the manuscript is commendable, and the revisions successfully elevate the paper to a publishable standard.

Author Comment: Thank you

Additional Questions:
1. Originality: Does the paper contain new and significant information adequate to justify publication?: The revised paper continues to provide novel insights into SMART technologies for mitigating construction health and safety risks. It effectively identifies unexplored areas such as underutilized technologies and introduces the "Fatal Five" concept, which adds value to the research.

Author Comment: Thank you

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: The literature section has been enhanced with additional sources to cover gaps previously noted.

Author Comment: Thank you

3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts, or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: The revised methodology clarifies inconsistencies noted earlier, such as the accurate depiction of included articles in the PRISMA flow diagram and correct citations of the PRISMA guidelines

Author Comment: Thank you

4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: The results are now well-organized, with the discussion better linked to specific findings.

Author Comment: Thank you

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: The revised conclusions elaborate on practical applications, public policy implications, and potential teaching uses.

Author Comment: Thank you

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the field and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: Clarity and readability have improved significantly.

Author Comment: Thank you

Regional Associate Editor
Comments to the Author:
(There are no comments.)

Author Comment: Thank you

SMART Technologies that Influence Construction Health & Safety Factors Risk Reduction in The Current Digital Era

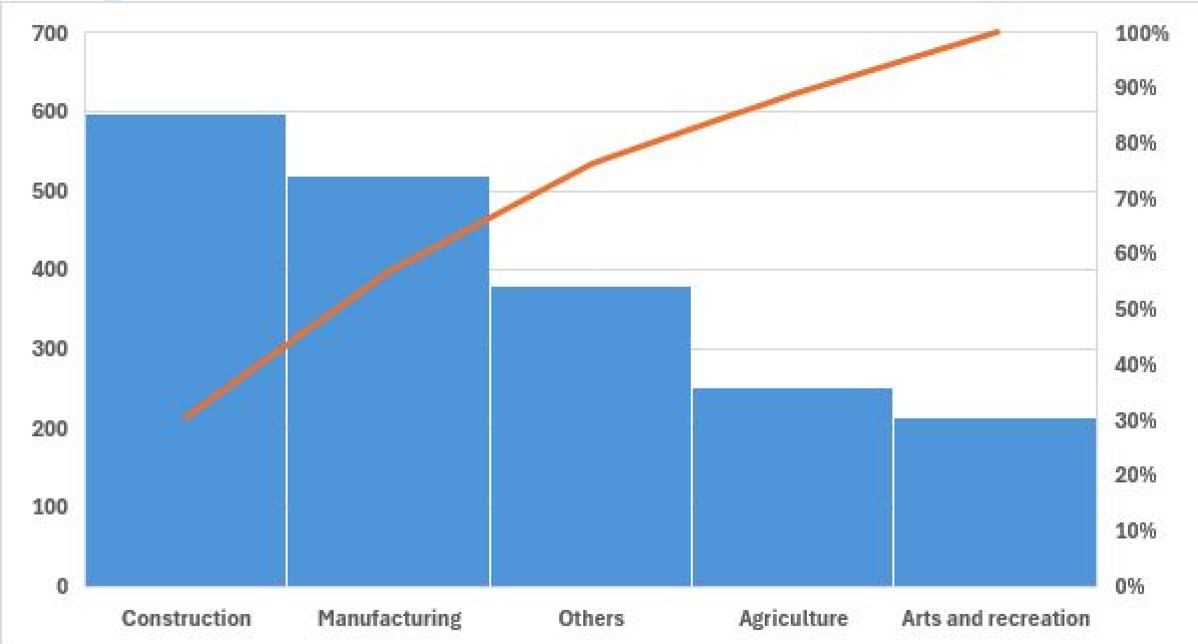

Figure 1: Industries with the highest numbers of injuries, illnesses and severe harm Source: Authors own work

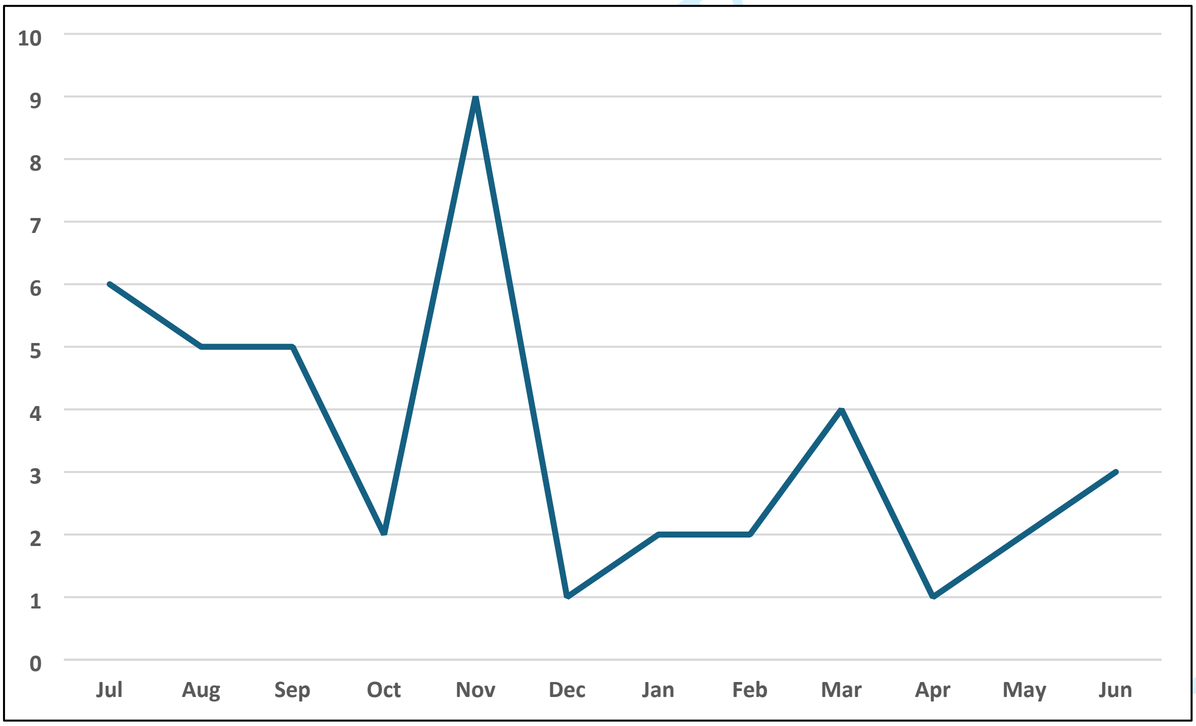

Figure 2: FFH (WorkSafe NZ, 2023) Source: Authors own work

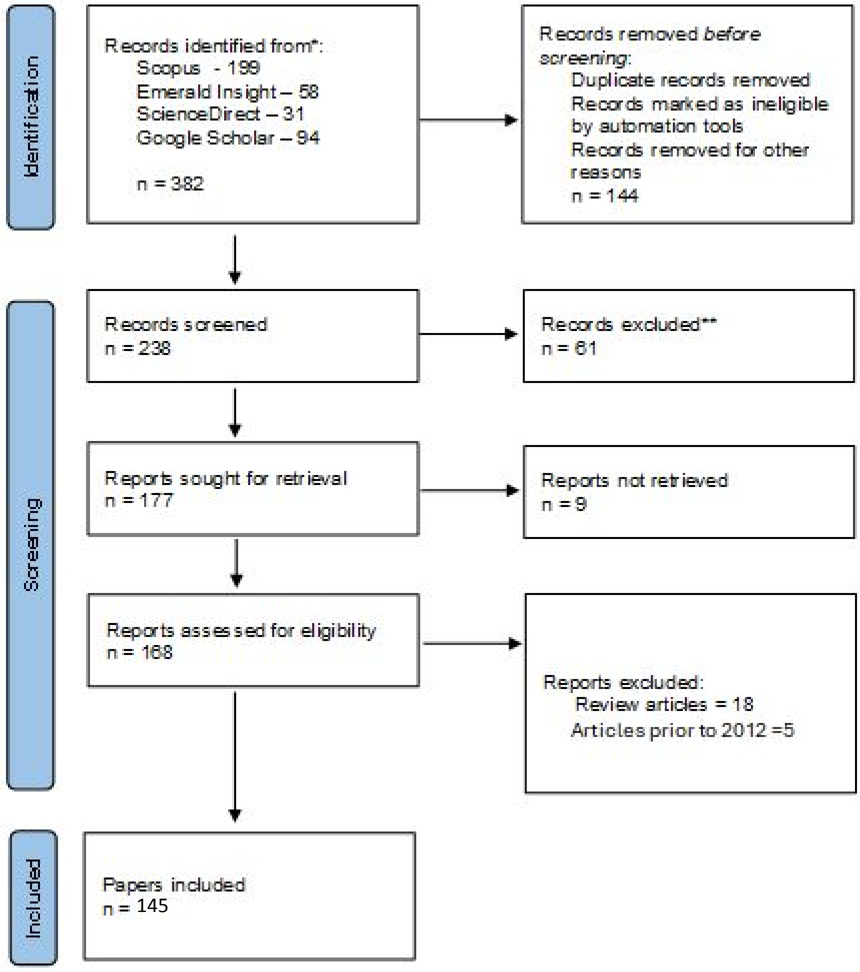

Figure 3: Identification of studies via database search Source: Authors own work based on Prisma guidelines

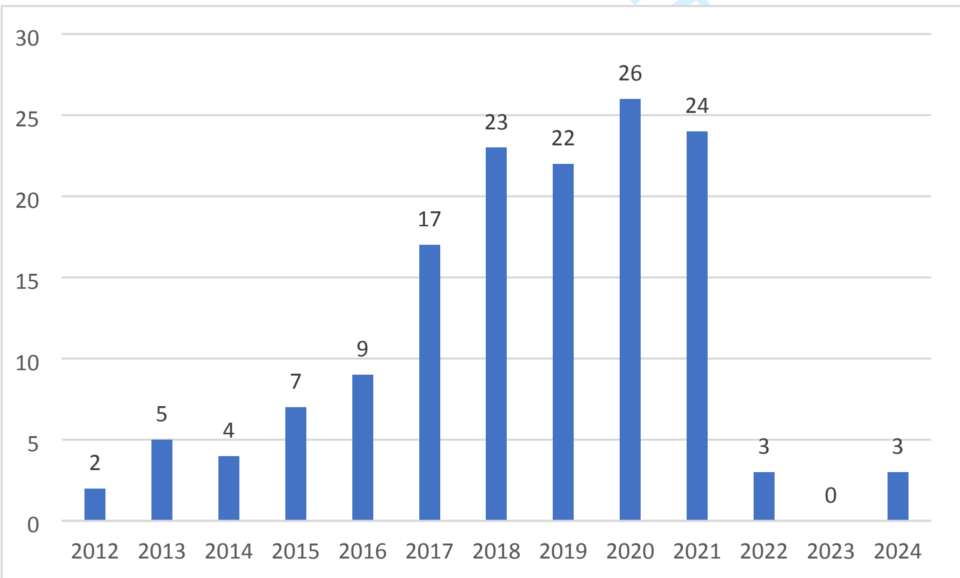

Figure 4: H&S Number of articles year-wise Source: Authors own work

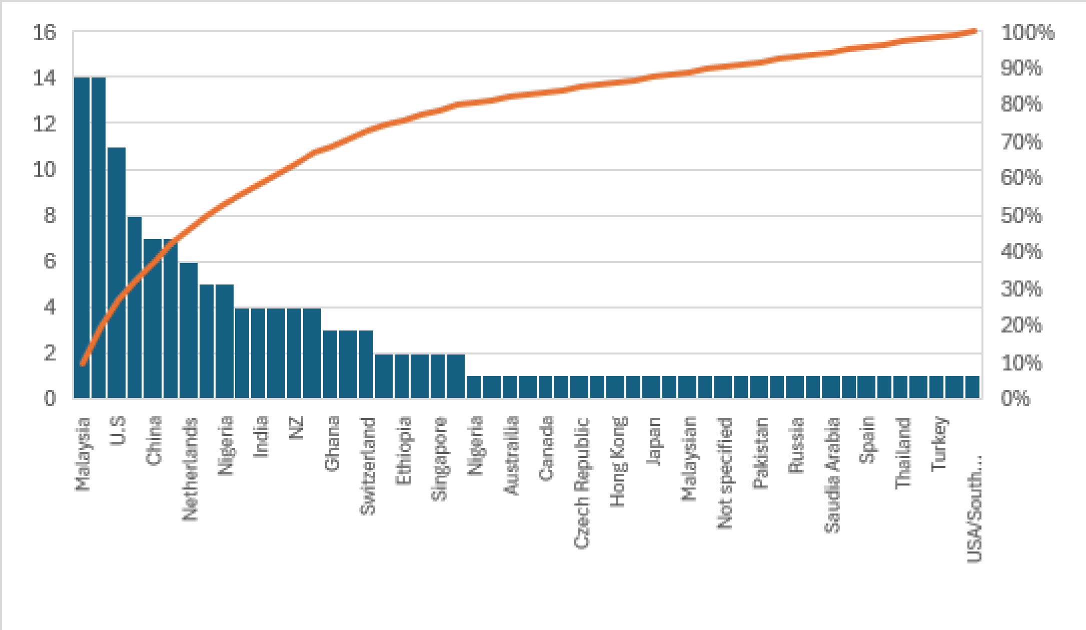

Figure 5: H&S articles published based on the countries Source: Authors own work

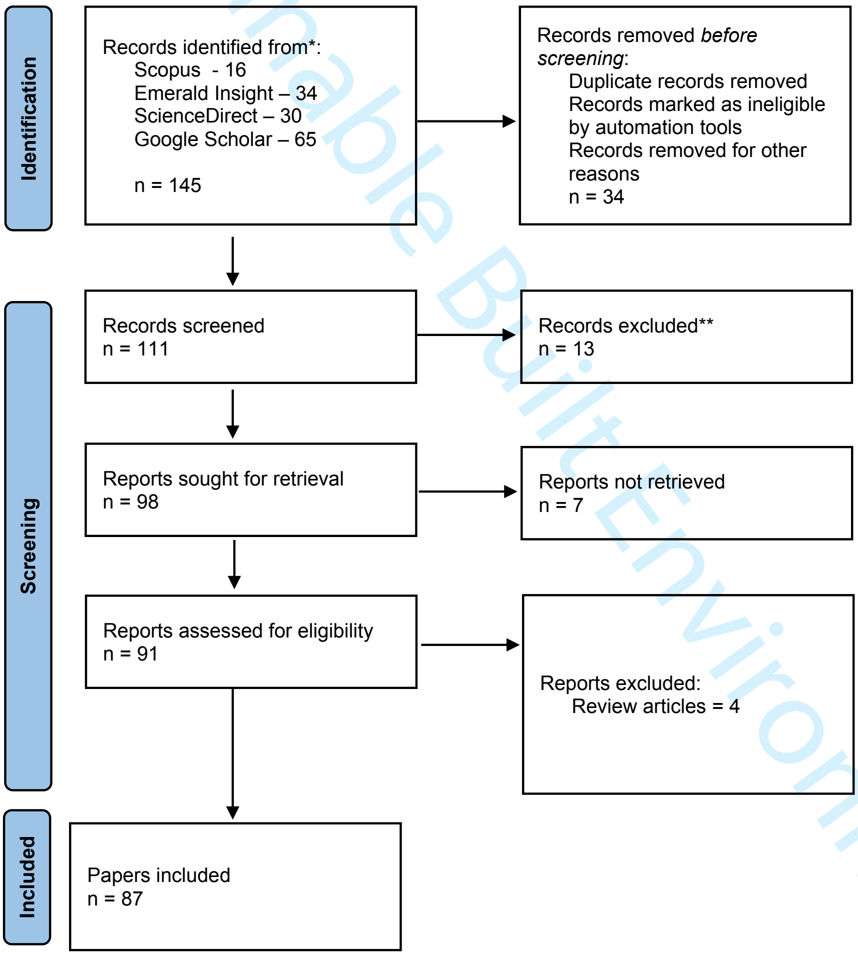

Figure 6:Identification of documents via database search for Keyword combination 2 Source: Authors own work based on Prisma guidelines (Prisma,2024)

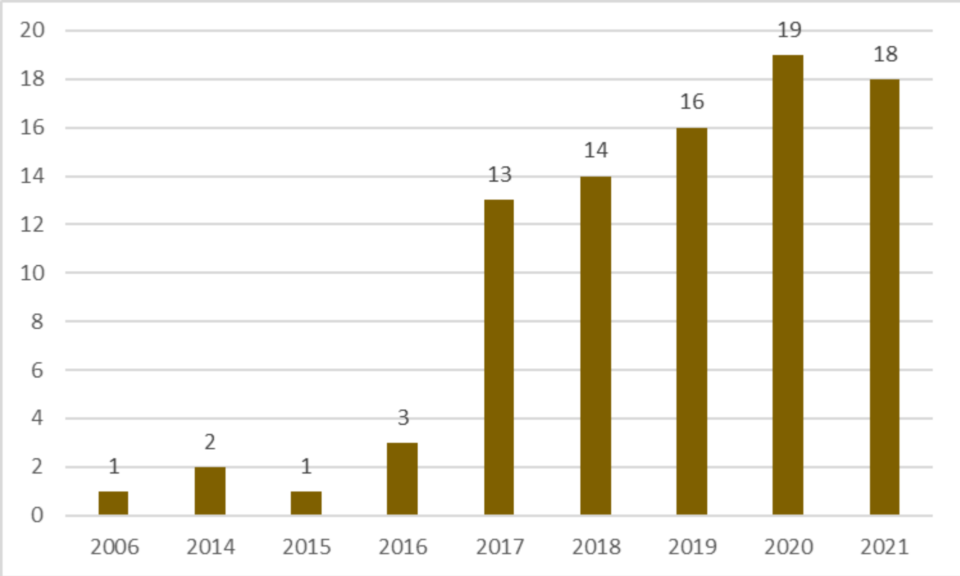

Figure 7: ST number of articles year-wise. Source: Authors own work

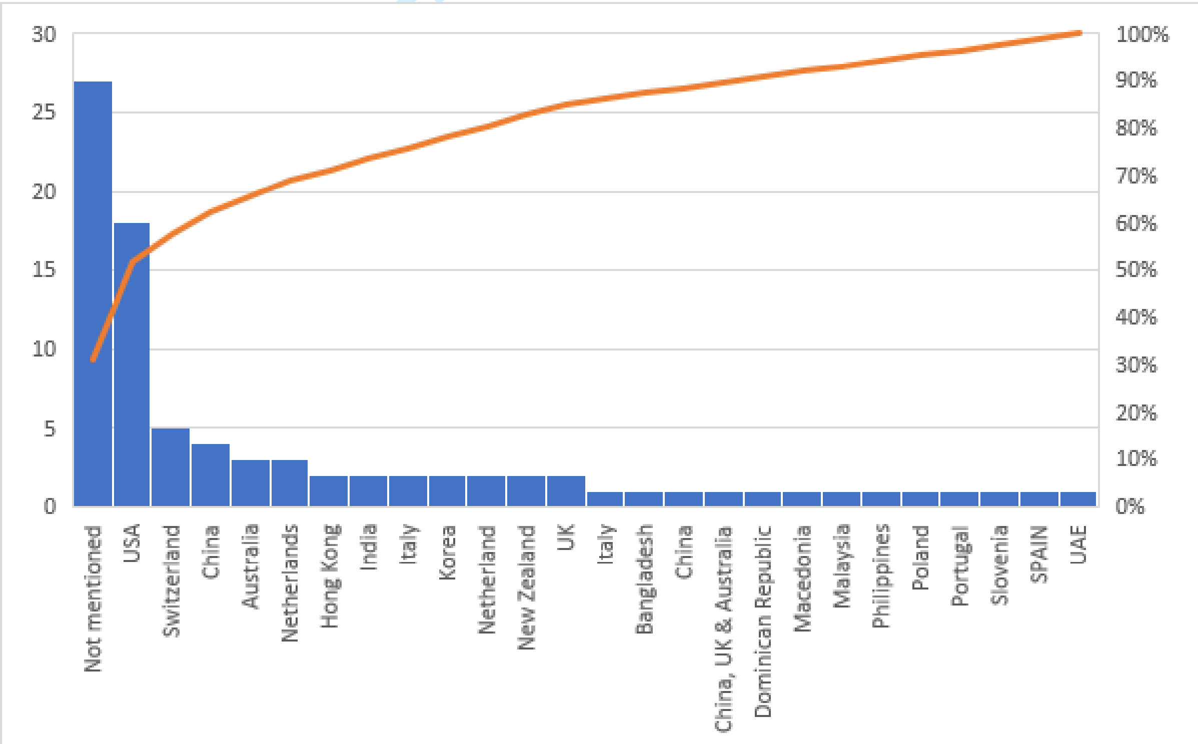

Figure 8 ST articles published based on the countries Source: Authors own work

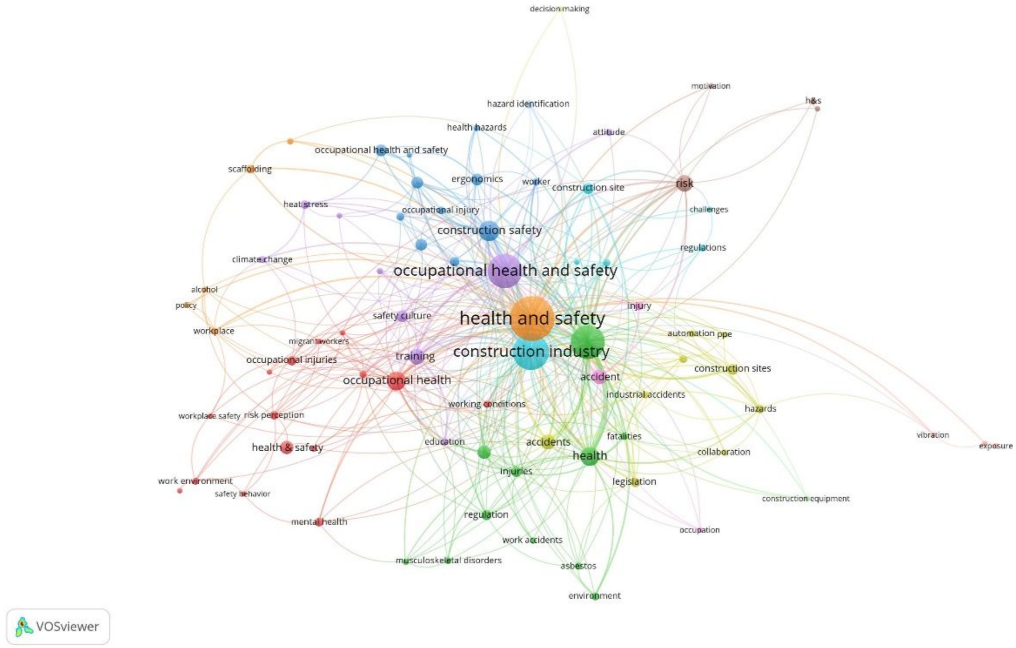

Figure 9:Visualization of keywords occurrence of H&S factors in construction   Source: Authors own work using Vos viewer

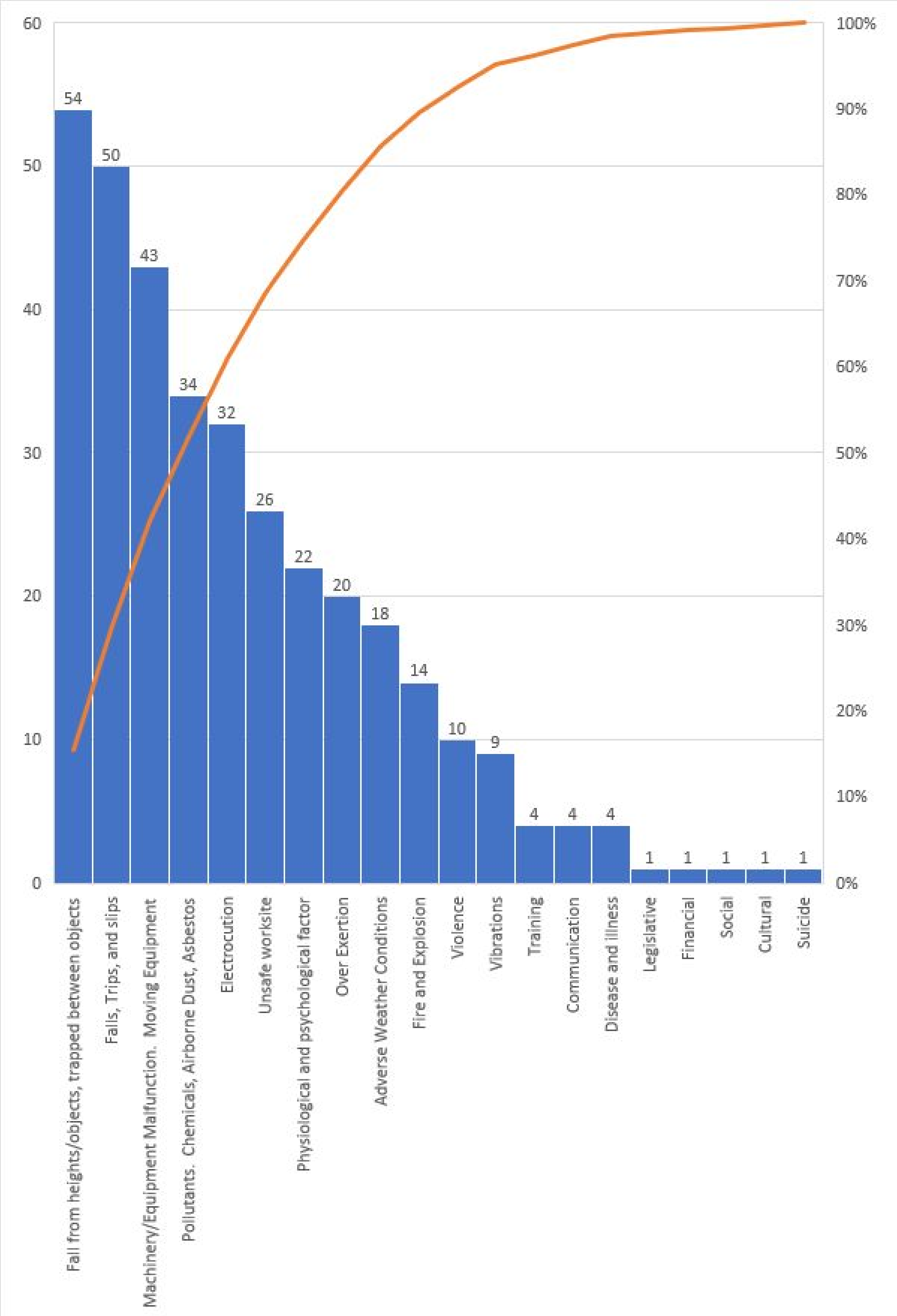

Figure 10 Pareto chart of factors affecting H&S in Construction Source: Authors own work

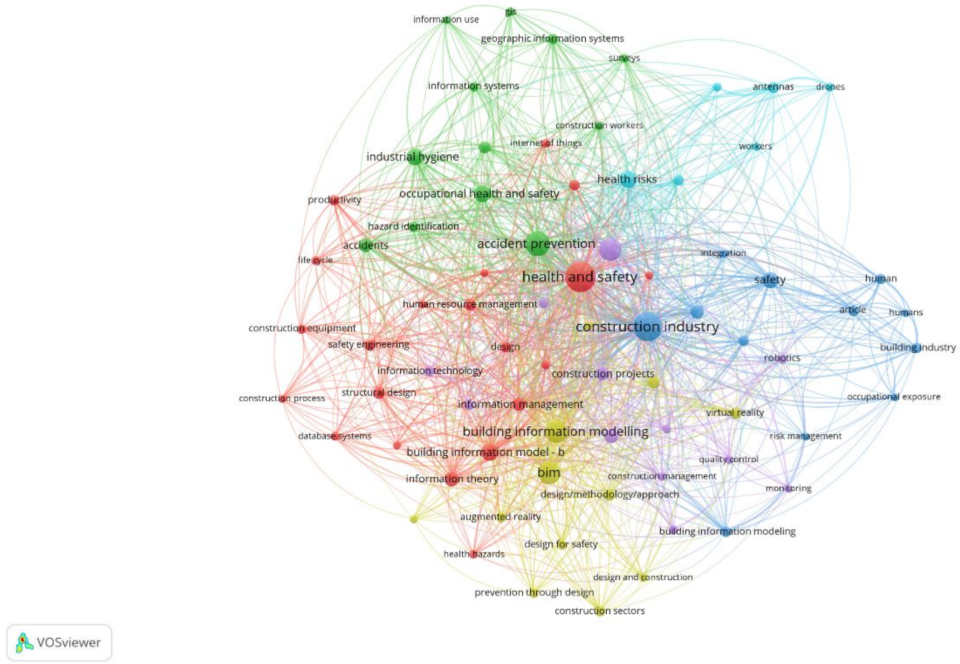

Figure 11: Visualization of keywords occurrence of H&S factors in construction Source: Authors own work using VOS viewer

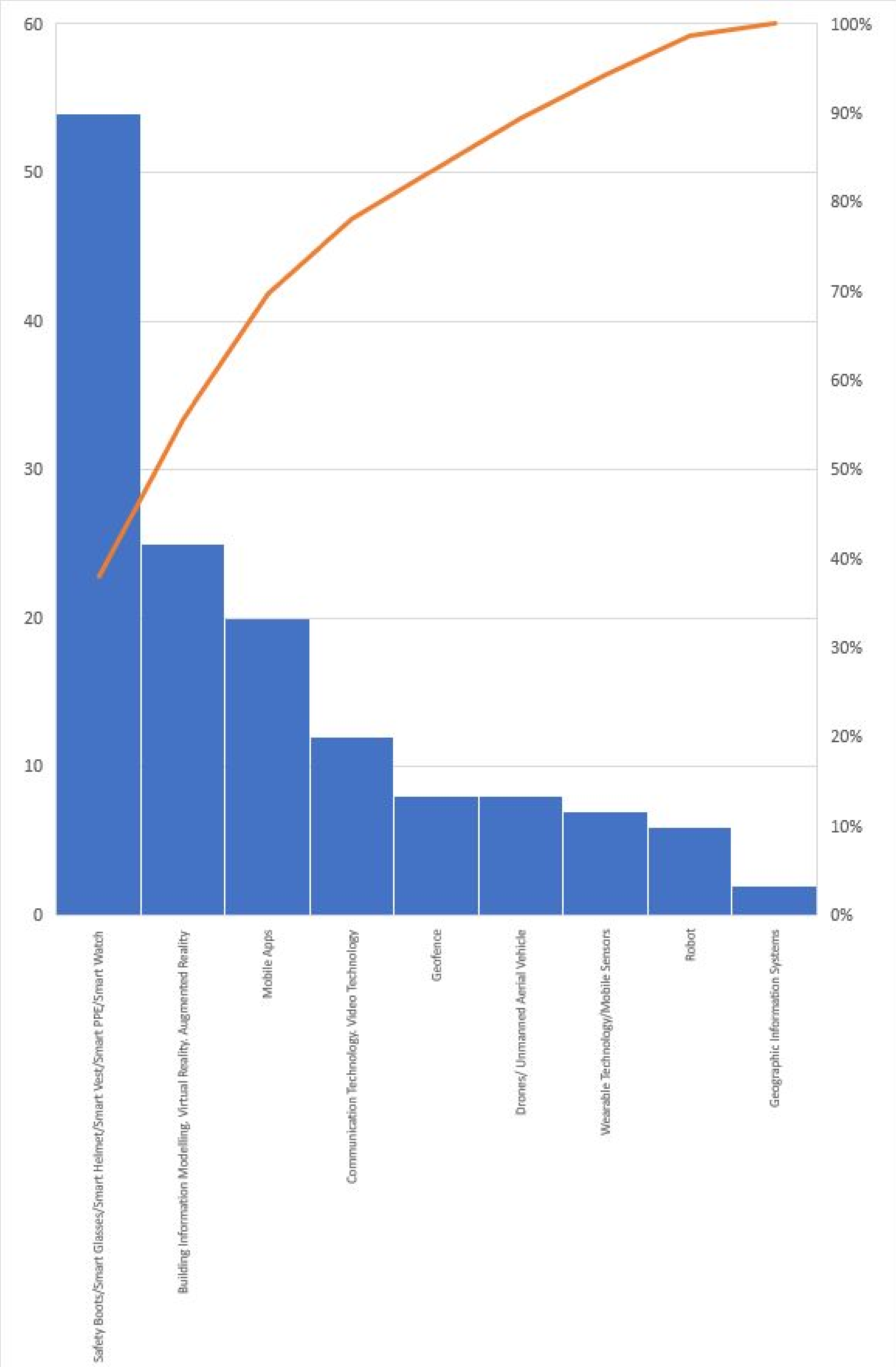

Figure 12: Pareto chart of SMART technology concerning H&S in construction Source: Authors own work

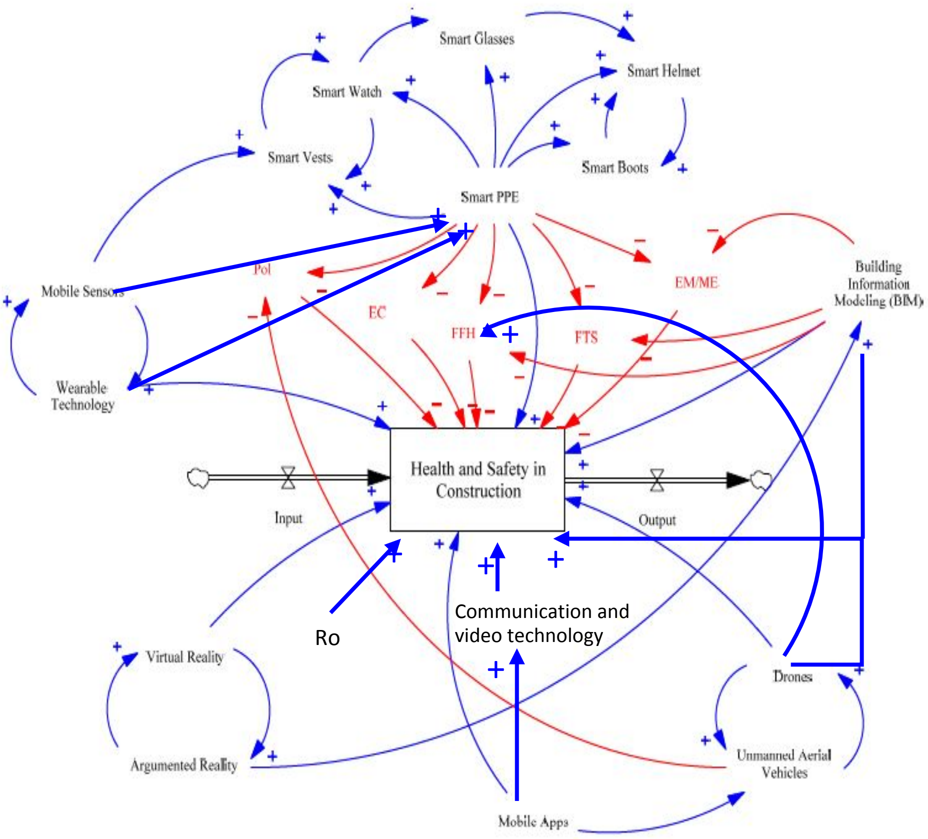

Figure 13 Interactions of factors affecting H&S and ST Source: Authors own work using Vensim software