www.cr.rwth-aachen.de
cr@ip.rwth-aachen.de

Editors:
Univ.-Prof. Dr.-techn. Sigrid Brell-Cokcan
Dr.-Ing. Thomas Adams

RWTH Aachen University
Chair of Individualized Production
Campus-Boulevard 30
52074 Aachen
Germany
www.ip.rwth-aachen.de

Editorial Assistance:
David Lukert B.Sc.

Original cover:
Lukas Kirner M.Sc.

Funded by BLE Seed Fund of Faculty 2 - Grant of RWTH Aachen University

The content of the book was created for teaching purposes as part of the Research Driven Projects course.

RWTH Aachen University
Templergraben 55
52066 Aachen

First published 2024

Available via the institutional repository of RWTH Aachen University:
DOI: 10.18154/RWTH-2023-08854

YE LU AND MIA OBRALIC

How to contribute to reducing fall fatalities on construction sites: Cloud Computing and On-Site Automation

ABSTRACT

The aim of this paper is to significantly reduce the incidence of accidents in the construction industry by discussing the possibilities of unconventional solutions to the problem of falling from heights in two different directions based on current technology: cloud computing and automation of on-site construction.

To explore more, a systematic literature review was conducted to understand the specific causes of fall accidents, and a new framework system was constructed to optimize the current measures. In developed countries, the accident rate of construction is decreasing, but in terms of accident risk, the construction industry is still the highest risk factor.

Doi: 10.18154/RWTH-2023-08860

Keywords: construction industry, fatal accidents, reduce falling fatalities, reduce, cloud, automation.

Image created with Adobe Firefly

1. Introduction

Compared with other industries, the construction industry is less industrialized, using traditional human resource-intensive manufacturing as a means. [1]. (See Figure 1) So until today, the construction manufacturing industry itself is inseparable from a large amount of manpower, taking over all aspects from the ground to the roof. The construction industry is one of the most dangerous industries in terms of safety. In the 10 years from 2009 to 2018, the number of deaths in various industries in the United States was 48,391, among which the number of work-related injuries in the construction industry was the highest, nearly one-fifth of the people were from the construction industry, and 8,792 people died (see Table 1 and Figure 1)[2]. Among them, falling is the main cause of accidents.

In recent decades, many countries have adopted many policy measures to try to reduce the accident rate in the construction industry[3]. For example, it is required to install fences in high-risk areas, and regular safety education is provided to construction workers. However, current traditional safety measures have not significantly reduced fatal accidents such as falls. Especially in countries with relatively low labor costs[4]. Even in developed countries, the accident rate of construction is decreasing year by year, but in terms of accident risk, the construction industry is still the industry with the highest risk factor[5].

This paper aims to substantially reduce the accident rate in the construction industry by discussing the possibility of unconventional solutions to the problem of falls on the basis of existing technologies in two different directions: cloud computing and automation of on-site construction. Concerning job site safety, decisions and trade-offs are made. To explore more, we conducted a systematic literature review to understand the specific c auses of fall accidents. And according to the conclusions drawn in the literature review, a new framework system is constructed to optimize the current measures to reduce the accident rate of construction sites.

2. Research methods

2.1 Determine the purpose:

In order to optimize the current measures to reduce the rate of fall accidents on construction sites, it is necessary to u

nderstand the reasons for frequent falls from heights, as well as the process and mechanism of their prevention in advance. Additionally, the limitations, strengths, and weaknesses of current solutions are being investigated. Based on the results of the

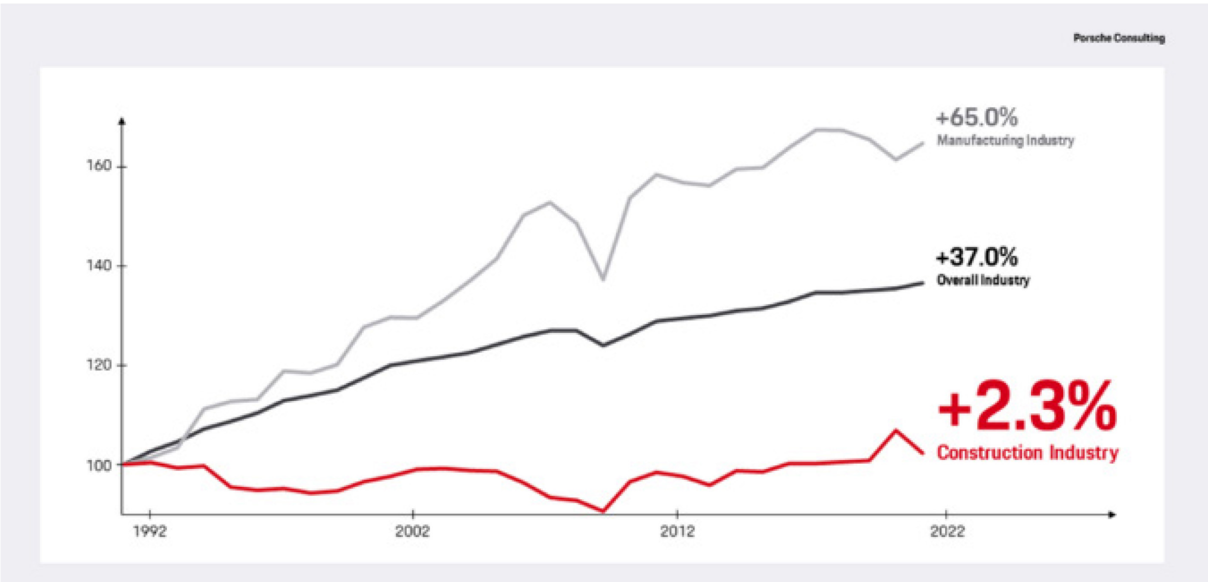

Figure 1. Labor productivity per hour worked in the construction industry in Germany lags significantly behind other sectors, but at the same time offers great potential for improvement

Year	Construction Industry	All Industries	Percentage%
2009	834	4551	18.33
2010	774	4690	16.50
2011	738	4693	15.73
2012	806	4628	17.42
2013	828	4585	18.06
2014	899	4821	18.65
2015	937	4836	19.38
2016	991	5190	19.09
2017	977	5147	18.98
2018	1008	5250	19.20
2019	1066	5333	19.99
2020	976	4764	20.49
2021	951	5190	18.32
Total	11785	63678	18.51

Table 1. Percentage of Deaths in the Construction Industry in Comparison with Total[1][2]

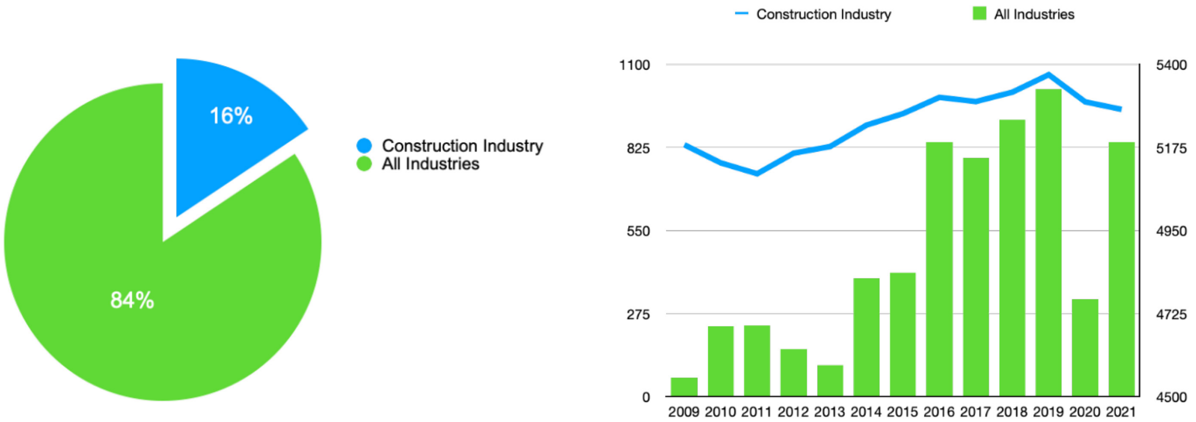

Figure 2. Percentage of Deaths in the Construction Industry in Comparison with Total Number of Fatali-ties across all the industries in the United States from 2009-2021

literature review, the height impact factors and high correlation results of the accidents caused by falls from heights are used as the basis for the establishment of the framework. And on this basis, start from two aspects of "optimizing existing technology and developing cloud processing system" and "on-site construction automation".

2.2 Select database

The data are extracted from official historical documents on construction site accident statistics in various countries as well as published literature. Considering the different results caused by different economic levels and policies, this paper selects the data of three countries for multiple comparisons. (See Table 2.) The choice of the United States, Germany, and China facilitates a variety of side-by-side comparisons: it demonstrates that safety in construction is not only a problem in low-cost labor-integrated countries, but also in developed countries and in countries with better safety systems. We will discuss this conclusion below.

2.3 Select keywords

Through the reading of a large number of literature (See Table 3.)and the first round of data analysis, it is concluded that falling is the primary factor leading to death, and the process and mechanism of preventing high-altitude falling accidents are further studied to find out the optimization plan[6]. earch keywords: combinations of ‘risk(s) of fall(s)’, ‘fall(s)’, ‘injury/injuries’, ‘risk(s)’, ‘fall(s) factor(s)/ factor(s) of fall(s)’, ‘Monitoring technology’, ‘digital device’, ‘cloud computing’, ‘automated assembly ‘and ‘construction industry’.

Countries	Data sources	Year
The United States	BLS: United States Bureau of Labor Statistics	2009-2021
Germany	AF: Statistik – Arbeitsunfallgeschehen	2010-2021
China	MHUR: Ministry of Housing and Urban-Rural Development of the People's Republic of China	2010-2021

Table 2. Data sources for collection of the national data.

Keywords	Reason	Number of literature
Fatality accidents national	Data sourse	10
Falling From Height national	Data analysis	7
Hazard Recognition	Safety solution	12
Reduce Falling Hazard	Safety solution	5
Automation Construction	Safety solution	13
Total		47

Table 3. The results of the first round of review of selected literature through the selection of keywords

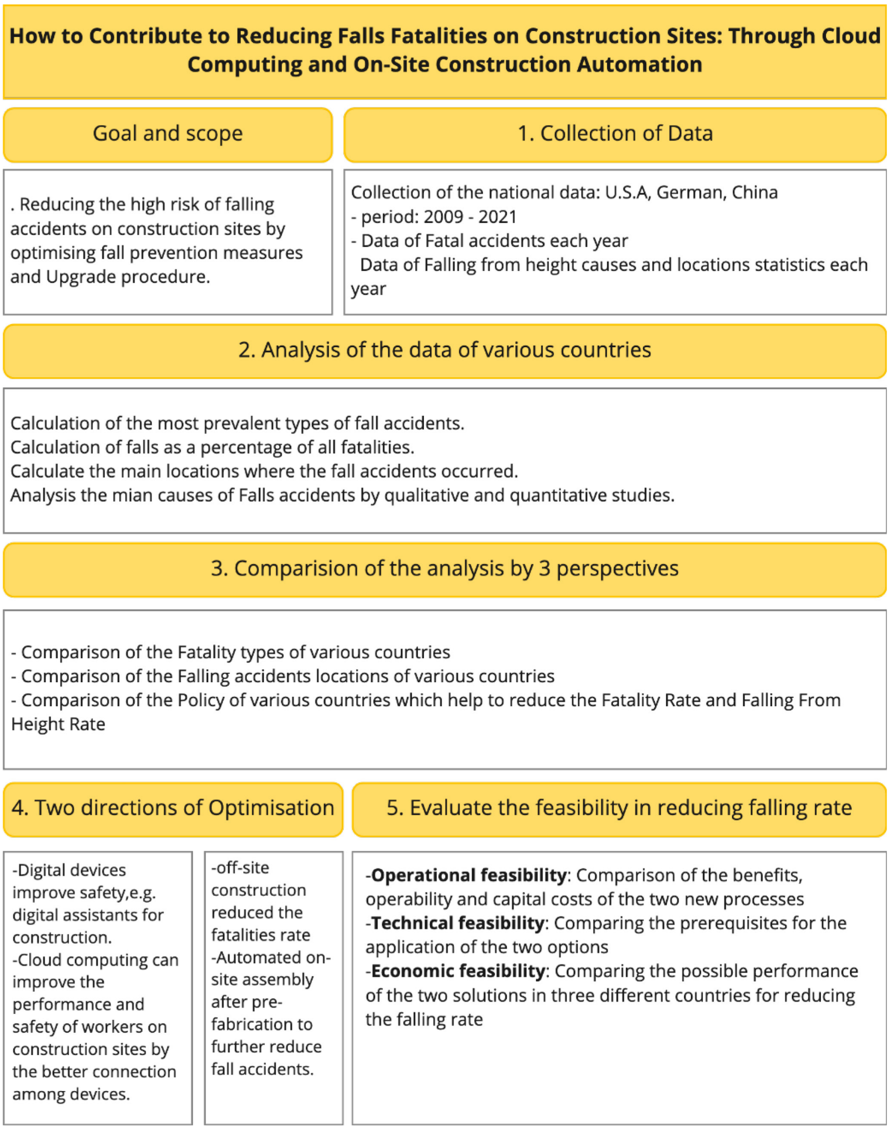

Figure 3. Research Process， made by YeLu

Year	FALLS, SLIPS, TRIPS	FIRES AND EXPLOSIONS	EXPOSURE TO HARMFUL SUBSTANCES OR ENVIRONMENTS	CONTACT WITH OBJECTS AND EQUIPMENT	VIOLENCE AND OTHER INJURIES BY PERSONS OR ANIMALS	TRANSPORTATION INCIDENTS	TOTAL
2011	**269**	**11**	**113**	**132**	**33**	**221**	**779**
2012	**294**	**9**	**104**	**139**	**37**	**266**	**849**
2013	**305**	**13**	**112**	**147**	**37**	**239**	**853**
2014	**363**	**15**	**124**	**118**	**48**	**265**	**933**
2015	**367**	**17**	**139**	**166**	**32**	**263**	**984**
2016	**388**	**11**	**140**	**170**	**42**	**278**	**1029**
2017	**389**	**16**	**147**	**139**	**59**	**261**	**1011**
2018	**340**	**17**	**175**	**170**	**62**	**273**	**1037**
2019	**418**	**7**	**171**	**152**	**66**	**284**	**1098**
2020	**371**	**9**	**175**	**158**	**57**	**262**	**1032**
TOTAL	**3504**	**125**	**1400**	**1491**	**473**	**2612**	**9605**

Table 4. Fatal accidents United States 2011-2020 [8]

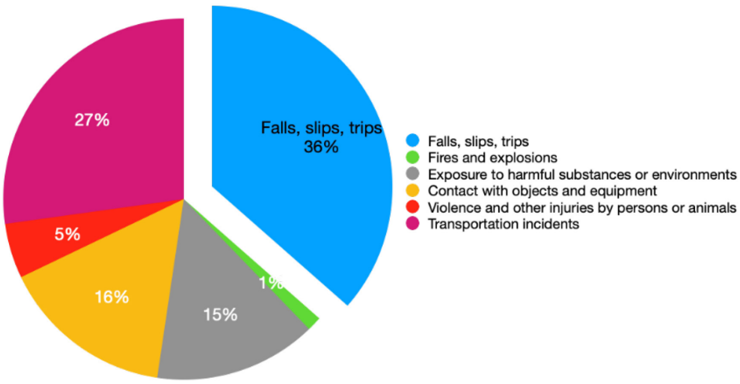

Figure 4. Fatal accidents United States 2011-2020 [8]

Search keywords: combinations of 'risk(s) of fall(s)', 'fall(s)', 'injury/injuries', 'risk(s)', 'fall(s) factor(s)/ factor(s) of fall(s)', 'Monitoring technology', 'digital device', 'cloud computing', 'automated assembly 'and 'construction industry'.

2.4 Research process

The project aims to reduce fatalities from falls on construction sites by optimizing fall prevention measures and upgrading procedures. It involves collecting and analyzing data on fatal accidents and fall-related statistics from the USA, Germany, and China between 2009 and 2021. The analysis will compare various aspects of fall accidents in these countries and assess the feasibility of reducing the fall rate through cloud computing, on-site construction automation, and digital assistants, ultimately aiming to improve worker safety and reduce fatalities.

3. Literature Review Findings

3.1 The most prevalent types of fall accidents on construction site

Falling from height

Among all known fatal accidents, falling from a height is the most important accident type, And the type of fall is falling from a height. The highest ranking among the three countries for fatalities is China, followed by the United States and then Germany. It can be seen that regardless of the impact of objective factors, such as policy, insurance, workers' education level and other factors that are

YEAR	STURZ ODER ABSTURZ	%	ABSTURZ VON BAULICHEN ANLAGEN IN DER HÖHE	%	TÖDLICHE UNFÄLLE ANZAHL	%	INSGESAMT FÜR TÖDLICHE UNFÄLLE
2010	**54**	**15,40**	**46**	**13,10**	**122**	**0,348**	**351**
2011	**47**	**13,10**	**66**	**18,40**	**144**	**0,401**	**359**
2012	**51**	**14,00**	**52**	**14,30**	**131**	**0,360**	**364**
2013	**63**	**18,60**	**44**	**13,00**	**136**	**0,401**	**339**
2014	**64**	**19,20**	**43**	**12,90**	**142**	**0,425**	**334**
2015	**57**	**17,30**	**29**	**8,80**	**117**	**0,356**	**329**
2016	**22**	**9,20**	**40**	**16,70**	**76**	**0,317**	**240**
2017	**19**	**7,50**	**44**	**17,50**	**80**	**0,317**	**252**
2018	**22**	**10,60**	**40**	**19,30**	**77**	**0,372**	**207**
2019	**11**	**7,30**	**43**	**19,70**	**73**	**0,335**	**218**
2020	**21**	**9,00**	**46**	**19,70**	**82**	**0,352**	**233**
2021	**16**	**5,90**	**29**	**10,80**	**67**	**0,249**	**269**
TOTAL	**447**		**522**	**AVERAGE**	**104**	**0,357**	**291**

Table 5. Fatal accidents Germany 2010-2021 Falling or collapses and Falling from structures at height parts (Arbeitsunfallgeschehen: Überblick Unfallschwerpunkte von Arbeitsunfällen bei betrieblicher Tätig-keit Arbeitsunfälle bei einer betrieblichen Tätigkeit 2010-2021) [9]

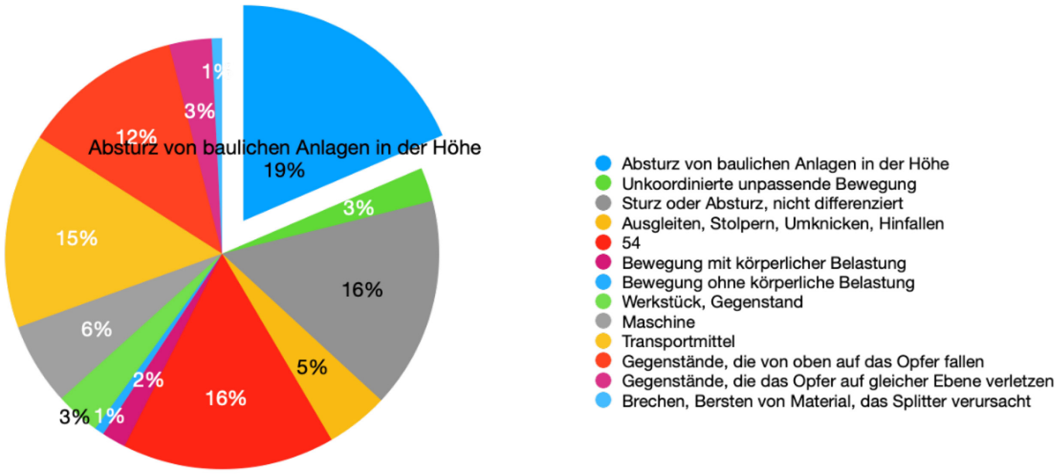

Figure 5. Fatal accidents tpyes Germany 2010-2021 [10]

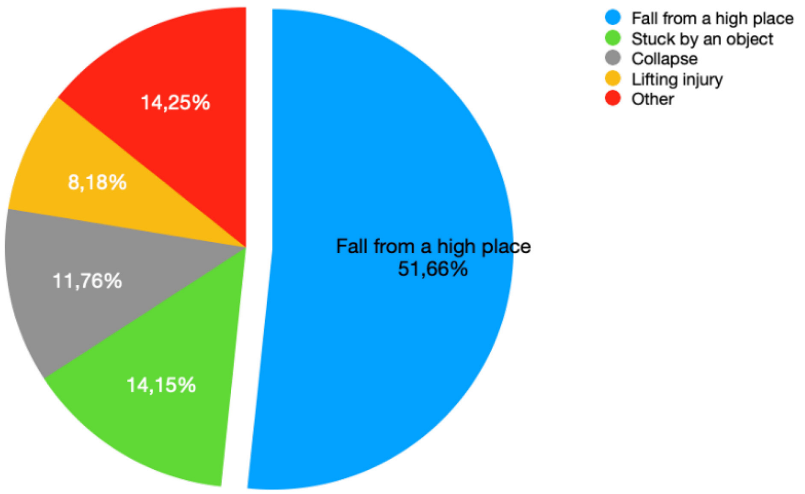

Figure 6. Fatal accidents types China 2021[11]

significantly different[7], falling is a high-risk accident that needs to be considered first.

3.2 The main locations of fall accidents on construction site

According to the comparison of the data in the table, we can see that in the United States, the roof is the most important place for falling accidents from high buildings, accounting for 33.3%. In Germany. Roofs, terraces, glass roofs, roof trusses, roof runners is the top 1 location of construction accident location, It accounted for 23.3% of the total. What China describes as "opening end edge" also refers to building edges that resemble uninstalled facades and roofs under construction[13].

All three countries show that the location of the fall is highly correlated with areas of large drop, as well as improvised facilities for climbing.

3.3 The main causes of fall accidents on construction site

Figure 7 ranks the macrovariables that directly affect the 'fall and injury risk' variable in decreasing order of link count and provides consistency with previous work. The top three causes of falls mentioned in this form include. (1) work surfaces and platforms (e.g. slippery surfaces, inappropriate concrete surfaces, slippery roofs, use of platforms, sliding of bamboo scaffolding and ladder bases); (2) worker safety behaviors and attitudes (e.g. safety procedures , perceived risk, assessment of risk, operating at unsafe speeds or playing at work); and (3) building structures and services (such as the stability of building frames and the reliability of building equipment). There is a high degree of agreement among the above three sets of national data[3]. Other highly researched and consistently rated factors contributing to fall risk include contractor/management safety practices, use of personal protective

Table 6. Fatal accidents types China 2021, Qingwei Xu and Kaili Xu[9]

Type	Fall from a high place	Stuck by an object	Collapse	Lifting injury	Other
Number	**2841**	**778**	**647**	**450**	**784**
Percentage%	**51.66**	**14.15**	**11.76**	**8.18**	**14.25**

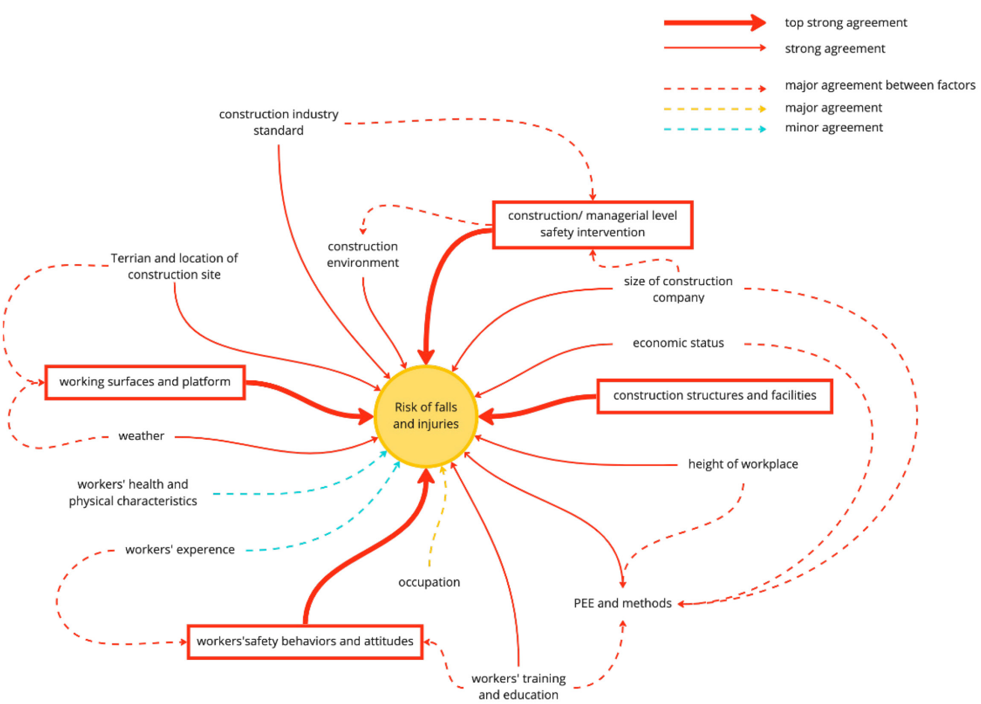

Figure 7. Causal relationships of macro-variables supported by qualitative and quantitative studies" (Hu etc., 2011, p. 403)[3][5]

equipment (PPE) and methods, worker health and physical characteristics, and construction site environment. Factors such as worker age, experience, and occupation are also often discussed, but there is less agreement on their impact[5]. The experience effect is compounded by the direct effect of experience on improving safety and the indirect effect due to overconfidence, which reduces adherence to safety procedures (Cellier et al., 1995; Hsiao and Simeonov, 2001; Lipscomb et al., 2003c; Bobick, 2004;

Haslam et al., 2005; Bentley et al., 2006; Choudhry and Fang, 2008; Lipscomb et al., 2008; Kaskutas et al., 2010). "Worker safety behavior and attitudes" was the primary influencing variable in terms of the number of studies that found the relationship between this variable and risk of falls. In addition, this variable is influenced by many other factors that directly contribute to the risk of falls as shown in Figure 6. Among them, "contractor/managerial level safety intervention" is also one of the most important variables directly affecting "fall and injury risk".[13]

3.4 Fall Prevention and Related Policies Are Enforced

People are using several measures to prevent fall accidents on construction sites, such as personal protective equipment (PPE), guardrails and safety nets, fall arrest systems, scaffolding and ladders, hazard assessment and training, housekeeping, and engineering measures[13].These are assure controls. for ensuring the safety of workers and reducing the number of fall accidents. Employers must implement and enforce these measures to create a safe working environment and prevent fall-related injuries and fatalities.

The US Occupational Safety and Health Administration (OSHA) sets minimum standards for protecting the health and safety of workers in construction and other occupational fields. OSHA's Regulation 1926.16 states that the prime contractor is generally responsible for workplace safety and each subcontractor remains responsible for maintaining the safety of its workers. Germany has a labour protection law called Staatliches Arbeitsschutzrecht, which includes the basic legal obligations of employers and employees. The laws are supported by the regulations or rules of a number of professional associations. For the German construction industry, it is mainly the Association for Employers' Liability Insurance in the Construction Industry ("BG Bau") that is responsible for maintaining and controlling safety.

BG Bau publishes regulations to set safety targets and define industry and process specific rules, including fall protection regulations. The construction site safety and health regulations (known as Baustellenverordnung BaustellV) have existed in Germany since 1998 and require contractors to provide a safe and healthy working environment. The involvement of a safety and health coordinator increases the total construction budget by 0.3-1%. However, the division of roles in construction safety can lead to problems. Communication of basic and required safety equipment can be an issue and often leads to problems on the project. In the United States, due to the different standards for the implementation of local state laws, there are relatively large loopholes in the implementation of the entire US construction industry. Implementation will be more difficult to monitor[14].

A similar system of joint and several liability is used in China to force vested interests to ensure the safety of construction workers by undermining their economic efficiency.The chances of compliance with the law are high once the number of people employed at a site reaches a certain level, but some choose to exploit loopholes in the legal system, leading to an increase in risk on small construction sites[5].

Overall, the factors that contribute to falls are relatively complex, but fall avoidance currently relies heavily on manual inspection and worker self-awareness. In the absence of strong and comprehensive legal requirements, this is all superficial[14]. And true compliance means significant expenditure of money and time in employing third party regulatory entities.

The aim of this paper is to intervene from 2 direct impact on the "risk of falls and injuries" variables, and there will be 2 directions of intervention strategies. Both are trying to reduce the influencing factors of this variable by non-manual inspection.

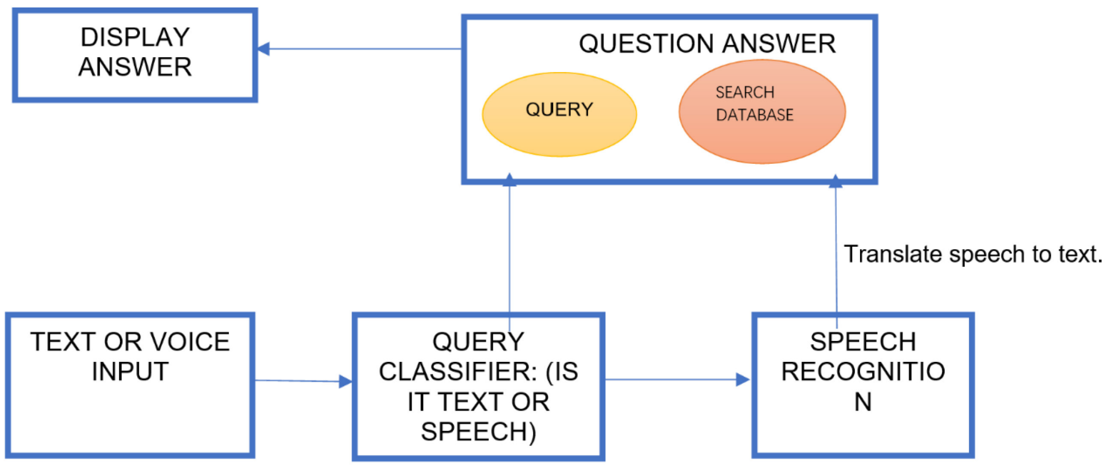

Figure 8 Architecture system of digital assistant [15]

4. Discussion: solution of reducing falling from height

4.1 cloud-computing

Current network infrastructure and system architecture

Digital devices can be used on construction sites to improve safety. Smartphones and mobile apps, wearable devices, and other IoT devices are among the most used digital devices.

Work and demand in the construction industry can be unpredictable, with many businesses relying on referrals and word-of-mouth for leads. During peak seasons, virtual assistants can also assist with construction, ensuring that safety protocols are followed and potential hazards are addressed as soon as possible. Construction professionals, such as project managers and superintendents, may become overburdened with work, making it difficult to prioritize workplace safety.

Figure 8 describes how the architecture of the digital assistant is designed to discern and efficiently process user inputs, whether presented as text or voice. Upon receiving an input, the system first employs a query classifier to determine its nature: textual or spoken. If the classifier identifies the input as spoken, the data is then directed to a speech recognition module which translates the vocal input into its textual equivalent. For textual inputs, or once the voice has been translated to text, the system further processes the query through a text analysis module. Here, the query is analyzed and matched against a database to extract relevant responses. Finally, the most pertinent answer is selected and presented to the user.

Using a construction virtual assistant can improve safety by assisting with construction-related tasks such as scheduling and tracking appointments, as well as managing communication and coordination.

Limitations and prerequisites of current systems and technologies

Processing requests and delivering results from local database can restrict the number of devices that are communicating, and the access of database is limited.

Effective communication is critical to the success of construction projects, especially when complex tasks, unpredictable work environments, and a diverse group of professionals are involved. Poor communication in these intricate projects frequently leads to faulty decisions and slow responses, which can result in serious safety incidents if not addressed. To avoid this, accurate, easily accessible, and up-to-date information must be disseminated to all project members, with a focus on construction site safety.

Discussion of solution

By making it possible to access real-time safety data and lowering the likelihood of incidents, construction sites' safety

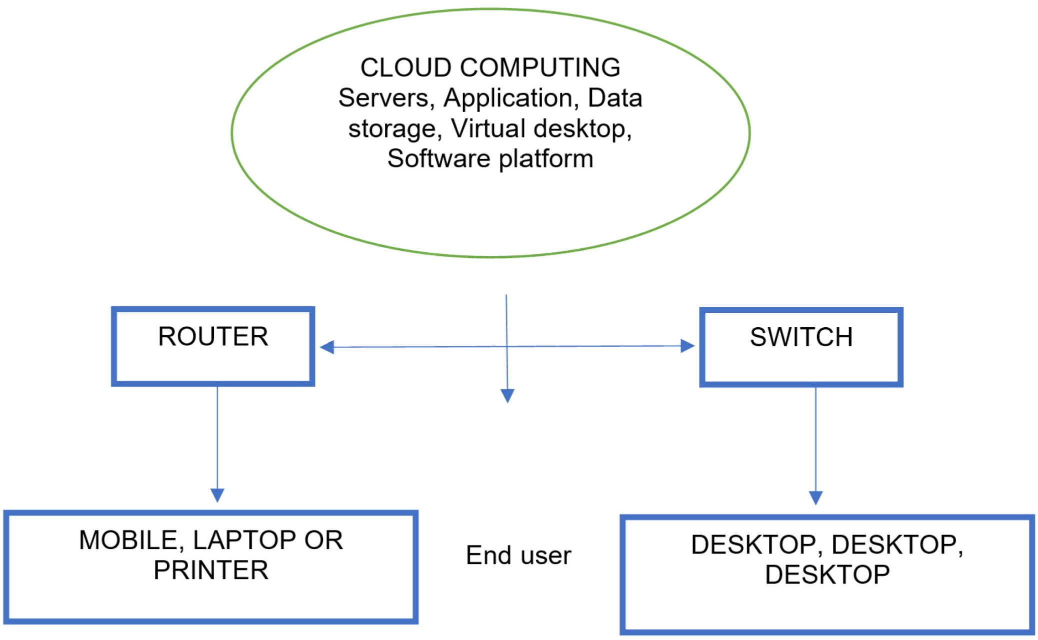

Table 8. Challenges, solutions, and operability of Cloud computing [16]

Challenges	**Solutions and operability**
Latency – delay of information	In order to avoid delays that could occur when using the Internet as a mode of transportation, construction companies could also be connected to the service provider via a dedicated link.
Trust, data privacy and security -increased fluidity of the security perimeter.	Implement internal data protection measures to prevent data leaks.
Data availability- where cloud provider can shut down their resources unexpectedly. Service Level agreement.	Service Level Agreement – 99.999% cloud service providers provide availability.
Poor broadband connectivity of construction site	with 5G network it can be solved

Figure 9. The network of Cloud computing [16]

performance is being enhanced using cloud technology. The use of cloud storage is also improving the accuracy with which safety risks for underground construction are collected and shared. In general, rapid construction safety decision-making relies on cloud data analytics. [3a] A discussion of the advantages and drawbacks of cloud computing can be found in Table 8.

Operability and cost control

One of the biggest security worries with the cloud computing model is the sharing of resources. The advancement of cloud computing is changing the horizon of information technology and ultimately turns the utility computing into a reality. However, it provides a large array of benefits, but also many challenges in this domain, such as automatic resource positioning, energy management, information security are only attracted the research community.[17]

These challenges are expected to be reduced as technology advances, and cloud computing adoption in construction is expected to increase.

According to the paper "Cloud Computing and its Technical Feasibility", an organization who intended to expand their services to different areas is better to go for cloud computing service in order to reduce cost. Depending upon agreement with the cloud computing service company all the data is

Server size	CPU Cores	RAM(GB)
Small	1	2
Medium	2	4
Large	4	8
XL	8	16
XXL	16	32

Table 9. Server sizes for Cloud computing [17]

Provider	Small ($)	Medium ($)	Large ($)	XL ($)	2XL ($)
Amazon	0.07	0.11	0.21	0.42	0.84
Microsoft	0.06	0.11	0.21	0.45	0.89
IBM SoftLayer	0.05	0.11	0.21	0.39	0.72
Google	0.04	0.09	0.18	0.35	0.71
Internap	0.01	0.02	0.04	0.09	0.18
1&1	0.01	0.04	0.07	0.18	0.18

Table 10. Hourly cost regarding cloud providers [17]

secured and taken care by that company it means any risk like loss, hacking of data.[18]

The vendor takes into account the hardware, setup, and maintenance costs of maintaining the network. They also look at how much it costs to provide storage, whether a company uses its own storage hardware or buys new equipment to meet its needs. Finally, the vendor takes into account computing costs like CPU costs and licensing costs for the client organization's operating system. Additionally, the provider takes into account the price of providing virtual RAM for each gigabyte utilized by the business. [17]

The cloud cost depends on the server size.

Flowcharts

Cloud computing can benefit while working at height at the construction site. Having a virtual assistant that is connected to a cloud computing service can decrease falls by increasing communication and analyzing data from all connected devices.

Figure 10 depicts the flowchart outlining the integration of a digital assistant with cloud computing for construction site tasks. Initially, the worker provides an input, either as text or voice, detailing a task at the construction site. This input is then directed to a query classifier, which determines its format: textual or spoken. If it's a spoken input, a subsequent step involves speech recognition to convert it into text. Once the text input is established, the system activates the smart device's tracking mechanism to pinpoint the worker's location and further prompts the worker with a series of safety-related questions. Upon completion, the gathered data, inclusive of the worker's responses, is analyzed using cloud computing. The system then provides feedback based on the worker's inputs and answers.

4.2 On-site construction automation in terms of safety.

Off-site construction and prefabrication

Construction work is performed in two different ways: traditional construction processes and offsite construction. Traditional construction methods involve manual labour and raw materials, while offsite construction involves prefabricated material and components fabricated and/or pre-assembled in a factory-type working environment. Traditional construction activities involve activities such as excavation, temporary or permanent formwork erection, concrete work, roofing, steel erection, screeding, ceiling erection, block laying, carpentry, plastering work, reinforcement work, painting work, and bricklaying[19]. These jobs are intrinsically hazardous in nature and impact negatively the health and safety of workers on construction sites. Prefabrication and preassembly can improve construction site working conditions by reducing significantly work to be done on site, and moving work away from construction

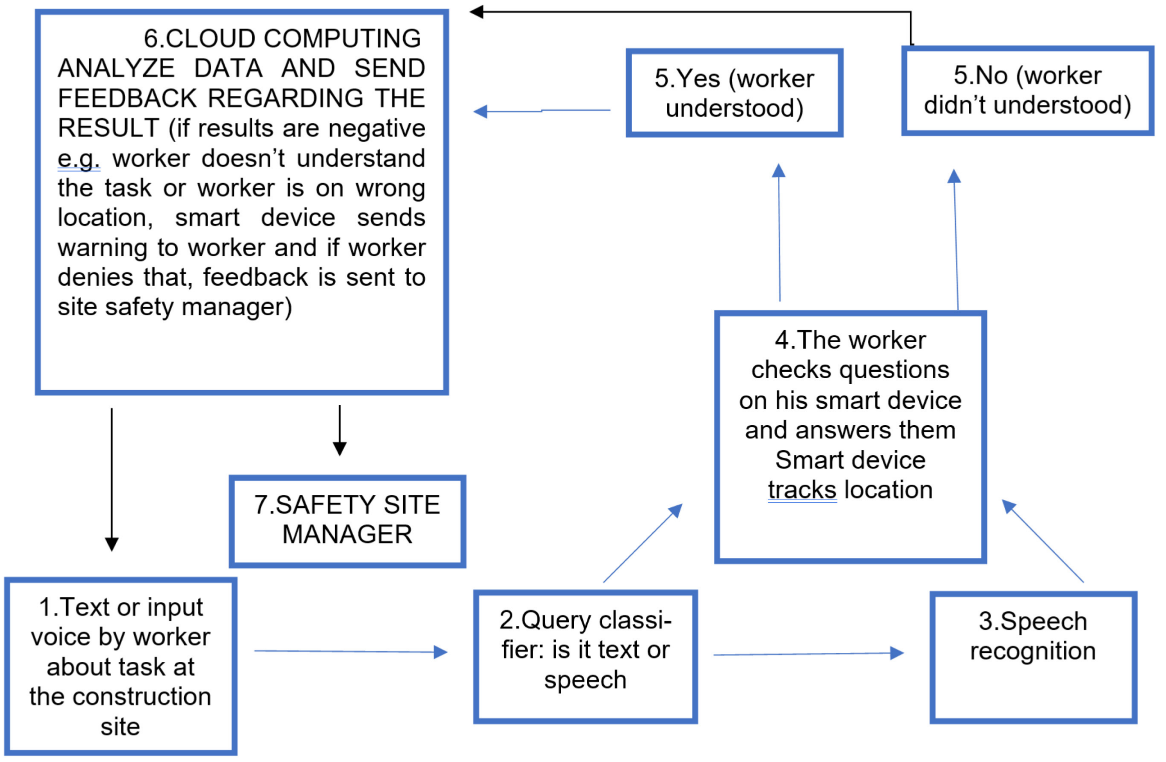

Figure 10 Flowchart of digital assistant with cloud computing

sites themselves could lead to less hazardous construction activities and, consequently, less risk[20]. Toole and Gambatese (2008) argued that prefabrication will not only improve health and safety but quality, productivity, performance, profit and the time frame for completion of the contract[21].

The findings backed up this theory by recognizing that using prefabrication might potentially lessen employees' exposure to steel reinforcement dangers and significant falls hazards connected with height-related tasks[20]. Prefabrication would imply a reduction in fall hazards by greatly lowering ascending and descending activities, repetitive body motions during onsite preparation of steel for strengthening, and silica dust, welding fumes, and organic solvents.

But even so, fatal accidents on construction sites have not been avoided.

Safety performance of remote construction sites

The most common type of injury in modular/prefabricated construction was 'facture', and the most common cause of accidents was 'fall'. According to report research, 44% of the causes were 'fall' and 36% were 'struck by object/ equipment(non-vehice)'[20]. Further analysis shows that 48.1% of the falling accidents occurred at the on-site stage. It is not difficult to see that even with the blessing of prefabricated construction, once it enters the assembly stage of the construction site. All the accidents about falling happened again. Basic on the analysis, the majority of the accidents (57.6%) occurred during installation of modular/prefabricated building or compents[20]. The result can be considered as evidence that off-site construction is potentially safer than on-site operations. It also shows that the fall accident cannot be completely avoided by reducing the time of on-site production only by prefabricating components without changing the way of using manpower to install on-site. The highest rate of 'fall' was 'falls from roofs'(34.5%), followed by 'falls from structures other than roofs' (25.5%)[20].Especially commercial buildings and super high-rise buildings, the lifting , moving and installation of heavy and large components is complex and dangerous. Although the risk of falling is reduced overall, the single-person risk factor of full-time workers assembling on site is increased[21].

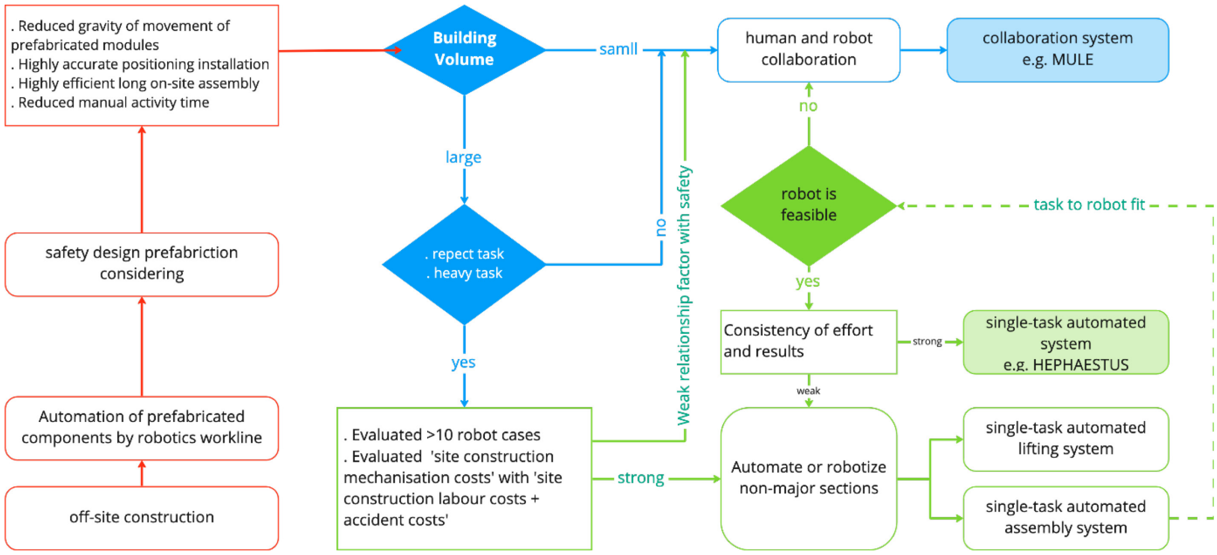

Figure 4. evaluation system workflow

Discussion of solutions

To sum up, freeing workers from some repetitive, high-risk and high-risk measures is of great significance for automated assembly in on-site construction. As discussed earlier in this article, there are a large number of primary and secondary factors in the causes of worker falls, and if all of these factors can be addressed, then the constraints on construction sites will also increase significantly. For countries with relatively expensive human resources, replacing some humans with machines for repetitive, high-risk and high-risk operations can actually reduce expenditures[22]. But for construction sites, they will be differentiated due to factors such as various environments and developers, so it is definitely uneconomical to simply automatically assemble a specific component, and it is necessary to develop an evaluation system first[23]. The most dangerous and repetitive items for a specific site are selected and corresponding groups and automation modules: robotic arms, feeding equipment, safety systems, etc. These automation modules are being developed by various academic institutions and commercial, such as the Hephaestus system, which aims to automate the on-site execution or installation process[24]. The system has the versatility to complete building structure scanning, prefabricated panel installation, painting, and curtain wall cleaning. , replacement of damaged components, repair of cracks, maintenance of solar cells and other tasks. (reference) In the future, it can be used to install the facade of some skyscrapers and even construct alien bases. The following is a simple evaluation logic framework. We even consider some large-scale weight-removing robotic arms to assist humans, such as the MULE system currently developed[25].

Operability and cost control of construction automation

Based on the data from the cases, all robots improved the accuracy of traditional tasks by 20-90% (55% on average) and reduced rework by over 50% compared to traditional techniques. Timetables improved by an average of 2.3 times, with productivity improving in eight cases, one increasing and one remaining the same. The median was 1.4 times, which is almost half the impact of manufacturing robots on productivity (an increase of 3.0)[22]. The fact that robots do not completely replace employees, but rather act as a tool to support or augment labour in dangerous or repetitive operations, is a key factor in this reduction in schedule impact. It is very important to further develop a fully automated autonomous system[25].

5. Evaluate the feasibility in reducing falling rate

The implementation of cloud-based information collection systems and automated on-site construction have the potential to reduce falling rate and worker deaths in the construction industry. Both processes offer benefits such as providing workers with real-time in-formation on site conditions and safety guidelines, Automating high-risk tasks, and reducing the risk of accidents and injuries. However, for the full potential of these processes to be realized, collaboration between workers and management, as well as the availability of resources, is necessary[26]. Compared to automated installation, the challenge of the cloud will be less, it is more software development, and technology upgrades for device connections. It does not affect the composition of the construction site at this stage. Especially in the training stage of workers, it is easier for them to understand and use.

In the United States, the construction industry is expected to adopt these technologies due to an increased focus on worker safety and efficiency. The regulatory framework supports the implementation of new technologies with a focus on reducing fatalities. In Germany, the construction industry is known for its high level of innovation and digitalization, with a strong emphasis on worker safety. The im-plementation of these technologies is expected to gain popularity and reduce casualties on construction sites.In China, the construction industry has developed rapidly but human resources are still relatively cheap, leading to slower adoption of new technologies. The government may enhance measures to implement safety regulations, but the cost of investment remains a factor. The performance of cloud-based information collection systems and automation may vary depending on the level of technology adoption, regulatory frame-work, and resource availability.

6. Conclusion

The analysis of the research process in this paper shows that falling is the number one cause of accidents in the construction industry, and human factors are the primary influencing factors. This identifies the forces acting on robots in construction, such as the need for construction to optimize productivity and cost, safety culture in construction incentivizing solutions to keep workers away from danger-ous tasks, and labor shortages. Other highlighted forces included available technology, quality requirements, willingness to adopt the technology, increased project complexity, and COVID-19 constraints. However, the imple-mentation of building automation at the cur-rent stage is still limited by the current technology and the low level of industrialization of the construction industry, especially in devel-oping countries. The unit cost of technology research and development and operation of building automation is much higher than the cost of fines caused by fatal accidents. Therefore, In the short term, the implementation of cloud computing to improve the safety behavior and attitude of construction workers to reduce the possibility of falling accidents is higher. The system development cycle is short, the cost is low, and the operability is high. In the future, the construction of the combination of the two will be unprecedentedly safe , will also develop more emerging occupations.

7. References

[1] Manish Venugopal, April 2020, ‘Construction Fatalities in the United Statesbetween 2009-2018 ’, International Journal for Research in Applied Science & Engineering Technology (IJRASET) ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429 Volume 8 Issue IV Apr 2020- Available at www.ijraset.com

[2] ‘NATIONAL CENSUS OF FATAL OCCUPATIONAL INJURIES IN 2021’, USDL-22-2309

[3] Shim, Y.; Jeong, J.; Jeong, J.; Lee, J.; Kim, Y. ‘Comparative Analysis of the National Fatality Rate in Construction Industry Using TimeSeries Approach and Equivalent Evaluation Conditions.’ Int. J. Envi-ron. Res. Public Health 2022, 19, 2312. https://doi.org/10.3390/ijerph19042312

[4] Workers’ rights: Labor standards and global trabe, https://www.brookings.edu/articles/workers-rights-labor-standards-and-global-trade/: Some countries, including China, might reject otherwise appealing trade deals that contain enforceable labor standards.

[5] Hu, Kun , Rahmandad, Hazhir , Smith-Jackson, Tonya and Winchester, Woodrow(2011) 'Factors influencing the risk of falls in the construction industry: a review of the evidence', Construction Man-agement and Economics, 29: 4, 397 — 416 To link to this Article: DOI: 10.1080/01446193.2011.558104 URL: http://dx.doi.org/10.1080/01446193.2011.558104
[6] Nadhim EA, Hon C, Xia B, Stewart I, Fang D. Falls from Height in the Construction Industry: A Critical Review of the Scientific Literature. Int J Environ Res Public Health. 2016 Jun 28;13(7):638. doi: 10.3390/ijerph13070638.PMID:27367706;PMCID:PMC4962179.](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4962179/)
[7] Shuang, Q.; Zhang, Z. Determining Critical Cause Combination of Fatality Accidents on Construction Sites with Machine Learning Techniques. Buildings 2023, 13, 345. https://doi.org/10.3390/build-ings13020345
[8] Fatal occupational injuries by selected worker characteristics and selected industry, All U.S., all ownerships, 2011 – 2020
[9] Statistik Arbeitsunfallgeschehen,2010-2020, Deutsche Gesetzliche Unfallversicherung (DGUV) Spit-zenverband der gewerblichen Berufsgenossenschaften und der Unfallversicherungsträger der öffentli-chen Hand, Mihail - stock.adobe.com
[10] Arbeitsunfallgeschehen: Überblick Unfallsch-werpunkte von Arbeitsunfällen bei betrieblicher Tätig-keit Arbeitsunfälle bei einer betrieblichen Tätigkeit 2010-2021
[11] Xu, Q.; Xu, K. Analysis of the Characteristics of Fatal Accidents in the Construction Industry in China Based on Statistical Data. Int. J. Environ. Res. Public Health 2021, 18, 2162. https://doi.org/10.3390/ ijerph18042162
[12] The Central People's Government of the People's Republic of China. 2020. Available online: http://www.gov.cn/flfg/2011-04/25/content_1851696.htm (accessed on 18 June 2020).
[13] Q.Zeng and J.H. Yoon,2022, 'The Optimized Process for Effective Decision Makings to Minimize Fall From Height (FFH) Accidents on Construction Site', 39th International Symposium on Automation and Robotics in Construction (ISARC 2022) qzeng41@gatech.edu, jyoon337@gatech.edu
[14] Jürgen Melzner , Sijie Zhang , Jochen Teizer & Hans-Joachim Bargstädt (2013): A case study on automated safety compliance checking to assist fall protection design and planning in building infor-mation models, Construction Management and Economics, DOI:10.1080/01446193.2013.780662
[15] Longo, F., Nicoletti, L. & Padovano, A. 2017, "Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context", Computers and Industrial Engineering, vol. 113, pp. 144-159. https://doi.org/10.1016/j.cie.2017.09.016
[16] Sururah, A. Bello, Lukumon O. Oyedele, Olugbenga O. Akinade, Muhammad Bilal, Juan Manuel Davila Delgado, Lukman A. Akanbi, Anuoluwapo O. Ajayi, Hakeem A. Owolabi 2021 "Cloud computing in construction industry: Use cases, benefits and challenges"Vol 122, February 2021, https://doi.org/10.1016/j.autcon.2020.103441
[17] L. Rosencrance, Breaking Down the Cost of Cloud Computing in 2023, 2022, https://www.techtarget.com/whatis/Breaking-Down-the-Cost-of-Cloud-Computing, last access 14.11.2023
[18] Rambabu.Bugatha (2015) "Cloud Computing and its Technical Feasibility" Journal of Multidisciplinary Engineering Science and Technology (JMEST) ISSN: 3159-0040 Vol. 2 Issue 4, April – 2015 https://www.jmest.org/wp-content/uploads/JMESTN42350567.pdf
[19] Omoseni Adepoju · Clinton Aigbavboa · Nnamdi Nwulu · Michael Onyia, 'Re-skilling Human Re-sources for Construction 4.0', https://link.springer.com/10.1007/978-3-030-85973-2

[20] L. Bikitsha1 and Prof. T.C. Haupt2, 'Impact of prefabrication on construction site health and safety: Perceptions of designers and contractors', https://www.researchgate.net/publication/327727819 [1] [1]

[21] Maryam Mirhadi Fard, Seyyed Amin Terouhid, Charles J. Kibert & Hamed Hakim (2015): Safety con-cerns related to modular/prefabricated building construction, International Journal of Injury Control and Safety Promotion, DOI: 10.1080/17457300.2015.1047865

[22] Cynthia Brosque1 · Martin Fischer1, 'Safety, quality, schedule, and cost impacts of ten construc-tion robots', Construction Robotics (2022) 6:163–186 https://doi.org/10.1007/s41693-022-00072-5

[23] Thomas Linner, Wen Pan, Rongbo Hu, Charlie Zhao, Kepa Iturralde, Meysam Taghavi, Julian Trum-mer, Marcel Schlandt and, Thomas Bock, 'A Technology Management System for the Development of Single-Task Construction Robots', Article in Construction Innovation · October 2019 DOI: 10.1108/CI-06-2019-0053

[24] Lorenzo Elia 1,*, Rubén Alonso 2 and Jesús Cañada 3, 'HEPHAESTUS—Highly Automated Physical Achievements and Performances Using Cable Robots Unique Systems', Proceedings 2018, 2, 558; doi:10.3390/proceedings2150558 www.mdpi.com/journal/proceedings

[25] Fopefoluwa M. Bademosi and Raja R. A. Issa, 03 January 2022, 'Automation and Robotics Technol-ogies Deployment Trends in Construction', under exclusive license to Springer Nature Switzerland AG 2022 H. Jebelli et al. (eds.), Automation and Robotics in the Architecture, Engineering, and Construction Industry, https://doi.org/10.1007/978-3-030-77163-8_1

[26] Wayne B. Gray, John Mendeloff,2022, 'Preventing construction deaths: The role of public poli-cies', Regulation & Governance (2022) doi:10.1111/rego.12486

[27] Building Radar, Digital Trend: Virtual Digital Assistants (VDAs), https://buildingradar.com/construction-blog/digital-trend-virtual-digital-assistants/, last access 14.11.2023

[28] Prajakta Patil and Chiradeep BasuMallick, What Is Cloud Computing? Definition, Benefits, Types, and Trends, 2022, https://www.spiceworks.com/tech/cloud/articles/what-is-cloud-computing/, last access 14.11.2023

[29] Sapna Jain, M Afshar Alam, 2017 "Comparative Study of Traditional Database and Cloud Computing Database", http://www.ijarcs.info/index.php/Ijarcs/article/viewFile/2935/2918

[30] Kamal Kant Hiran, Ruchi Doshi, Dr.Rakesh Rathi, 2014 " Security & privacy issues of cloud & gridcomputing networks" International Journal on Computational Sciences & Applications (IJCSA) Vol.4, No.1, February 2014https://www.researchgate.net/publication/273011196_Security_Privacy_issues_of_Cloud_Grid_Computing_Networks , International Journal on Computational Science & Applications 4(1):83-91

[31] Q.Zeng and J.H. Yoon " The Optimized Process for Effective Decision Makings to Minimize Fall From Height (FFH) Accidents on Construction Site" 39th International Symposium on Automation and Robotics in Construction (ISARC 2022)