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The Integration of Internet of Things (IoT) Technology into Fire Evacuation Plan in High-rise Buildings

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ABSTRACT

With the rapid socio-economic development and urbanization, the emergence of high-rise buildings effectively alleviates the problem of tight urban land use but also increases the pressure of fire escape due to their large vertical drop, complex structural functions, and dense population. With the increasing popularity of Internet of Things (IoT) technology, there is a growing interest in using IoT technology for high-rise building fire escape. IoT for high-rise building fire escape refers to the application of IoT technologies and devices to improve the effectiveness and efficiency of evacuation procedures in fire incidents. This research investigated the issue of high-rise building escape to investigate a feasible, the aim is to explore the advantages of IoT technology for fire escape in high-rise buildings and to evaluate the effectiveness of IoT technology in real-life scenarios of fire evacuation plans for high-rise buildings. To achieve this goal, this research used a quantitative method to examine the impact of IoT technology to systematically integrate into fire escape methods and technical systems. The study of fire escape systems for high-rise buildings provided a quick understanding of fire hazards, helped people quickly choose the correct escape route and minimize reaction time, while easing people's panic. The use of IoT technology provided new ideas and methods for high-rise fire escape and provided a case reference for the application of IoT technology in life. The results of this study showed that IoT technology had great potential to enhance fire escape mechanisms in high-rise buildings. The integration of IoT technology into fire escape implementation offered a great opportunity to improve the effectiveness and efficiency of high-rise building evacuation procedures. By harnessing the capabilities of IoT devices and sensors, a more proactive and intelligent approach to fire escape could be achieved.

1. Introduction

According to the continuous progress of urbanization, this has led to an increasing demand for high-rise buildings [1]. The emergence of tall buildings brings both solutions and challenges. These soaring buildings effectively solve the problem of limited land in the city, but they also bring complex problems related to fire safety and evacuation. The intricate interplay between verticality, structural

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complexity, and population density highlights the need for innovative approaches to enhancing fire escape procedures in tall buildings [2]. According to incomplete statistics, China currently has 220,000 high-rise buildings, of which super-high-rise buildings of more than 150 meters account for 87 per cent of the global total, and there are 61 of the top 100 buildings with a height of more than 300 meters [3]. With the increasing number of high-rise buildings, the problem of fire escape from high-rise buildings is becoming more and more prominent. One avenue that has garnered much attention in recent years is the integration of Internet of Things (IoT) technologies, which promises to redefine fire escape strategies in high-rise buildings. The central focus of this research revolves around the comparative analysis of IoT technologies with traditional fire protection systems, particularly about fire escape facilitation in high-rise buildings [4]. In addition, the study aims to evaluate the practical performance of IoT technologies in specific fire evacuation scenarios in high-rise buildings. These research questions guided the study to explore the potential benefits of IoT technologies and their applicability in ensuring the safety of people during fire incidents.

1.2 Problem Statement

The issue of fire escape becomes increasingly crucial in safety management as the number of high-rise structures rises. Traditional fire escape methods may lead to untimely evacuation and improper choice of escape routes when facing the challenges of high-rise buildings, threatening the lives of residents [5]. However, IoT technology offers new solutions for fire escape in high-rise buildings. By connecting sensors, devices, and networks, IoT technology can monitor and intelligently warn of fire incidents in real time, providing more information support and guidance. This means that residents and firefighters can detect and act on fires earlier, shortening evacuation time, improving escape efficiency, and reducing fire risk.

Currently, there is limited research available in China regarding the practical application and benefits of IoT in high-rise building fire escape. Therefore, this study aims to bridge this gap and investigate the untapped potential of IoT technology in enhancing fire escape strategies for high-rise buildings. Simultaneously, through systematic comparison of the distinctions between IoT technology and conventional firefighting methods, it will offer decision-makers valuable information support and a scientific foundation for decision-making [6].

1.3 Research Aim

The main objective of this research is to investigate the challenges of evacuating high-rise buildings and explore how IoT technology can enhance fire escape procedures compared to conventional fire safety systems. Additionally, the study aims to uncover the potential benefits of implementing IoT technology, driving advancements in intelligent fire protection systems, and ultimately improving overall safety and efficiency during emergency evacuations. Simultaneously, this study evaluates the real-world effectiveness of IoT technology in the fire evacuation plan for high-rise buildings, offering decision-makers a scientific foundation and practical guidance. The findings of this study will enrich the field of smart fire technology and enhance urban fire safety practices. It will also improve the management of fire safety in urban buildings, ultimately creating a safer and more secure living environment for both residents and the public.

1.4 Research Objectives and Research Questions

i. Research questions

What benefits does IoT technology offer in comparison to conventional fire protection systems for facilitating fire escape in tall buildings?
How well does IoT technology perform in practical situations concerning fire evacuation plans for high-rise buildings?

ii. Research objectives
To explore the benefits of IoT technology for fire escape in high-rise buildings
To evaluate the effectiveness of IoT technology in real-life scenarios of fire evacuation plans for high-rise buildings.

1.5 Scope of research

This study primarily concentrates on tall buildings, specifically those with a height of 10 to 30 stories. The focus will be on incorporating cutting-edge IoT technologies into fire evacuation strategies for tall buildings, with particular emphasis on fire escape measures. A comparative examination will be conducted between IoT technology and conventional fire protection systems for fire escape in tall buildings to assess their respective advantages and limitations. Additionally, the study will evaluate the practical applicability of IoT technology in real-life situations.

2. Literature Review

2.1 Introduction

This section begins by clarifying relevant concepts. It describes the unique attributes of high-rise building fires, including the rapid spread of flames, the complexity surrounding evacuation procedures, and the constraints inherent in firefighting. In addition, the concept of the Internet of Things (IoT) is introduced, with its interconnected framework that facilitates seamless object-to-object communication via the Internet. The research then delves into the realm of traditional fire evacuation strategies for high-rise buildings. These strategies are based on encouraging independent evacuation and providing necessary assistance; however, this research also highlights the limitations inherent in traditional approaches to effectively respond to the multifaceted challenges posed by high-rise building fires. Ultimately, this study turns its focus to contemporary research efforts in high-rise building fire evacuation. By combining the inherent capabilities of the Internet of Things with fire protection systems, this emerging paradigm holds the promise of real-time situational updates and intelligent evacuation strategies.

2.2 High-rise Building Fires

High-rise building fire refers to a catastrophic event resulting from uncontrolled combustion occurring in a confined space and period [7]. High-rise building fire has the characteristics of rapid spread of fire, evacuation difficulties and fighting difficulties, once the fire, the temperature rises very quickly in the closed type of building, toxic fumes quickly filled with corridors, coupled with high-rise building evacuation distance, evacuation of the time required is long, the evacuation of personnel is easy to crowded or even blocked, resulting in the evacuation of the personnel to slow down the speed of evacuation. Personnel poisoning, room interest death or fire deaths have occurred repeatedly. Numerous incidents of fires in tall buildings reveal that the current methods of fire rescue for such structures are inadequate to keep up with the advancements in high-rise building construction.

2.3 Concept and Development of IoT

The Internet of Things (IoT) is an interconnected system that links diverse objects through the Internet, facilitating seamless communication and interaction among them. Zhao *et al*., [8] outlined the integration of Internet of Things (IoT) technology and its potential benefits in improving fire evacuation efficiency for high-rise buildings in the IoT era. Patel *et al.,* [9] proposed that in IoT, an object can be any object with a unique identifier and capable of communicating over a network, including sensors, devices, machines, cars, home appliances, buildings, plants, and animals, etc., which can be interconnected by collecting and exchanging data through sensors, chips, and communication technologies to achieve intelligence, automation, and smart decision-making.

2.4 Traditional Fire Evacuation of High-rise Buildings

In conventional tall buildings, ensuring safe evacuation during fire incidents has consistently remained a crucial concern in building safety management. Lay [10] studied them in terms of traditional evacuation strategies. It is proposed that individuals who can move independently should be encouraged to evacuate on their own, and that they should be provided with adequate assistance. To this end, a 'behavioural design' approach is proposed for these elderly facilities: understanding behaviours and needs in emergencies; designing systems to interact with them in emergencies; and testing solutions in real-life environments or using validated simulators. （Analysing the actions and firsthand accounts of six individuals who evacuated from Buildings 1 and 2, Xiong *et al*., [11] compared simulated traditional fire evacuation methods with fire evacuation methods using IoT technology. To attain highly efficient evacuation procedures at the global evacuation safety level, a coordinated control approach was adopted by integrating the Human Evacuation Route Optimization Model (HEROM) with the Fire Prevention and Joint Control System (FPJCS). This integration allowed for intelligent coordination and optimization of evacuation routes and safety measures. Ding *et al*., [12] enhanced the modelling of pedestrian movement in staircases of tall buildings during standard fire evacuation scenarios. Explored the variables impacting fire incidents in tall buildings to develop a comprehensive evaluation framework for fire occurrences, including fire safety infrastructure, evacuation effectiveness, fire prevention measures, and building fire safety protocols [13].

2.5 Application of IOT in Fire Evacuation of High-rise Buildings

Hostetter and Naser [14] Investigation of how people behave and evacuate during a fire incident at the Cook County Government Building in Chicago. Different strategies to enhance fire safety measures in tall office buildings are explored. Drawing from the information about fires in tall buildings, this study analysed fire incidents using the Accident Tree Analysis (ATA) technique, in combination with the core principles of safety systems engineering. This approach helped us gain insights into the occurrences of fire accidents and their underlying causes; the main causes of the fire accidents were detailed, and the importance of the basic accidents was arranged [15]. [16] Intelligent fire prevention and disaster relief system based on IoT using IoT technology. To solve these problems, an IoT and fire rescue based early warning system was proposed [17]. This paper examines the factors affecting fires in high-rise buildings and develops a comprehensive assessment framework for fire incidents in such buildings. The key factors include the availability of fire safety equipment, the effectiveness of evacuation plans, the building's fire prevention measures, and the overall management of fire safety [18]. Advanced fire and rescue systems that incorporate smart technology can offer real-time updates on the current situation, send alarms, and provide evacuation guidance,

all aimed at enhancing fire and rescue capabilities [19]. By combining modern automated sensing and communication systems [20] , these integrated systems explore the fusion of human evacuation route optimization models with fire prevention and control mechanisms. A new intelligent evacuation sensing system using IoT technology is established, and a case study is illustrated. Dong *et al*., [21] Integrate the technology of IoT with a self-developed smart fire evacuation system that identifies fires by analysing received fire connection signals to determine the optimal routes for safely evacuating people from fire areas.

3. Methodology

3.1 Introduction

This chapter outlines the approach taken to investigate the integration of IoT technology with fire evacuation plans for high-rise buildings. The study employs a quantitative research methodology, aiming to explore the benefits of IoT technology over traditional fire protection systems for high-rise building fire escape. Additionally, it evaluates the actual effectiveness of IoT technologies in real-life fire evacuation scenarios for high-rise buildings, and ultimately, offers valuable recommendations for improving fire evacuation procedures in these structures. The participants of this study consist of residents of high-rise buildings, fire rescue personnel, fire evacuation specialists, and relevant organizations.

3.2 Overview of the Research Approach

In developing fire evacuation plans for tall buildings, the selection of suitable research approaches plays a pivotal role. Quantitative analysis is widely recognised here for its ability to analyse large-scale datasets, identify patterns, and establish statistical relationships [22]. In this research, this study adopt a quantitative approach to investigate how IoT technologies can be effectively integrated into fire evacuation plans for high-rise buildings. This study aim to explore various data collection methods, analyse the data gathered, and interpret the results, providing valuable and comprehensive insights to enhance the field of study.

As a research methodology for the following reasons: 1. To collect objective, measurable, and standardized numerical data through surveys, questionnaires, and measurements. 2. To provide empirical evidence to analyse large data sets and identify important trends and influencing factors. 3. To provide a rigorous framework to examine variable relationships, validate research questions, and generalize results to a larger population. In this research, this study aim to explore various data collection methods, analyse the data gathered, and interpret the results, providing valuable and comprehensive insights to enhance the field of study.

Used a quantitative approach to explore the views of various stakeholders regarding the integration of fire evacuation plans with IoT technology for high-rise buildings. The main objectives were to uncover the benefits of using IoT technology for fire escape in high-rise buildings, evaluate its effectiveness in real-life fire evacuation scenarios, and ultimately reduce the risks associated with such evacuations. The findings from this study will provide valuable data to support the integration of IoT technology into fire evacuation plans for high-rise buildings.

3.3 Research Design

This study consists of two main research objectives:

i. To explore the benefits of IoT technology for fire escape in high-rise buildings.

ii. To evaluate the effectiveness of IoT technology in real-life scenarios of fire evacuation plans for high-rise buildings.

To accomplish these goals, this study need to gather previously unidentified and pertinent information for thorough examination. To achieve this, this study employed a survey using questionnaires as our primary means of data collection. This approach allows us to gain a comprehensive insight into the viewpoints, experiences, and thoughts of the involved parties. The questionnaire flow in this chapter is shown in Figure 1:

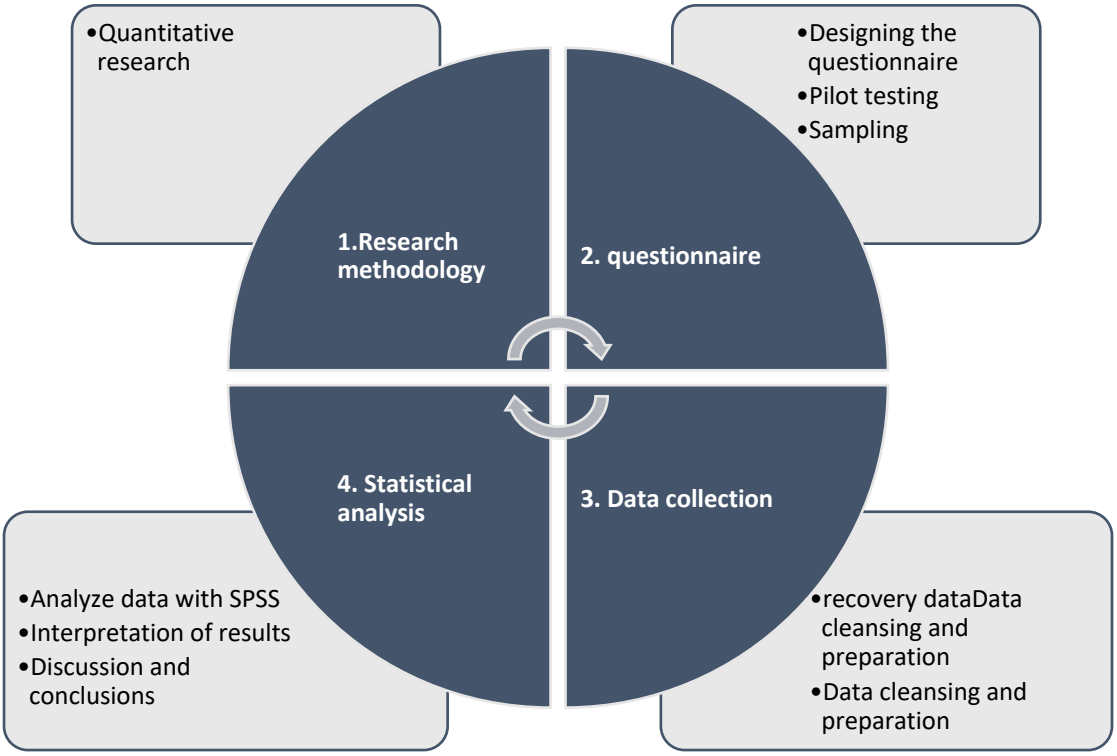

Fig. 1. Flow chart of questionnaire

In a study on the integration of IoT technologies with fire evacuation plans for high-rise buildings, it is crucial to determine an appropriate sample size to ensure the representativeness and reliability of the findings. The determination of sample size should consider factors such as the study design, the required level of precision, and the availability of resources [23]. As the need for representative statistical samples in empirical research continues to grow, it becomes critical to find effective sample size determination methods. In order to fill an existing research gap, this study used Table 1 to determine the number of participants needed for this study to ensure that the sample size was appropriate for the specific population under investigation [24].After considering the study's scope and geographic area, 384 participants were identified as an appropriate sample, effectively representing the target population. This sample size guarantees meaningful and relevant findings regarding the integration of fire evacuation plans in high-rise buildings, making a valuable contribution to the field of research.

Table 1
Table to determine the sample size of the finite population [25]

N	*S*	*N*	*S*	*N*	*S*
10	10	220	140	1200	291
15	14	230	144	1300	297
20	19	240	148	1400	302
25	24	250	152	1500	306
30	28	260	155	1600	310
35	32	270	159	1700	313
40	36	280	162	1800	317
45	40	290	165	1900	320
50	44	300	169	2000	322
55	48	320	175	2200	327
60	52	340	181	2400	331
65	56	360	186	2600	335
70	59	380	191	2800	338
75	63	400	196	3000	341
80	66	420	201	3500	346
85	70	440	205	4000	351
90	73	460	210	4500	354
95	76	480	214	5000	357
100	80	500	217	6000	361
110	86	550	226	7000	364
120	92	600	234	8000	367
130	97	650	242	9000	368
140	103	700	248	10000	370
150	108	750	254	15000	375
160	113	800	260	20000	377
170	118	850	265	30000	379
180	123	900	269	40000	380
190	127	950	274	50000	381
200	132	1000	278	75000	382
210	136	1100	285	1000000	384

Note.—*N* is population size.
S is sample size.

In this study, participants will be selected from a target population that includes stakeholders such as high-rise building residents, fire rescue personnel, fire evacuation specialists, and representatives of organizations associated with the field. By involving individuals from various roles and positions, our goal is to obtain a holistic understanding of fire evacuation in high-rise buildings, gaining valuable insights from multiple perspectives within the industry. By adopting various data collection methods from different viewpoints, this study can achieve a more holistic grasp of the real-world implementation of IoT technologies in fire evacuation plans for high-rise buildings. This approach will lead to a more convincing and trustworthy conclusion for our study. At the same time, the broad coverage of the target population will also ensure greater feasibility and applicability of the study's findings in real-world applications.

In the paper on fire evacuation integration in high-rise buildings, a random sampling method was used as a technique for selecting a subset (sample) of participants from a larger population of interest. A well-designed sampling method ensures that the selected sample accurately represents the characteristics, perspectives, and experiences of the wider population so that the findings and conclusions drawn from the sample can be generalized to the population. The ability of random sampling to fulfil the assumptions of statistical tests allows researchers to make meaningful inferences about the wider population based on sample data. Random sampling is more efficient, provides a reasonably representative sample size, and saves time and cost compared to other sampling methods. As a result, selecting samples randomly is the most suitable approach for this research.

3.4 Data Collection

In this research, this study will employ a mix of primary and secondary data gathering techniques to investigate the benefits of integrating IoT technology into high-rise building fire evacuation procedures. Additionally, this study will evaluate how effectively IoT technology performs in real-world fire evacuation situations for high-rise buildings. This study will employ a diverse range of approaches, including surveys, on-site observations, simulation experiments, and comprehensive literature analysis, to gather precise and dependable data [26]. The main goal of the study is to use these data to gain insights into the effectiveness of IoT technology in fire evacuation of high-rise buildings and to provide an effective basis for the optimisation of integration solutions. These data can provide insights into what affects fire escape, and these collected data are to be quantitatively analysed and conclusions drawn.

3.5 Statistical Analysis

In this research, the quantitative analysis will be conducted utilizing the Statistical Package for the Social Sciences (SPSS), which is a powerful statistical analysis software that can process and analyse the quantitative data collected, and the use of SPSS to calculate the descriptive statistics of the sample will help to understand the basic characteristics of the sample [27]. Descriptive analysis is a valuable method that is particularly applicable in the field of fire escape from high-rise buildings. It helps to summaries relevant data and provides a clear and concise overview of the data to help researchers understand the status of fire evacuation in high-rise building projects.

3.6 Preparation of questionnaire

The questionnaire was in the form of a Likert scale, which is a widely used evaluative measurement tool to collect respondents' attitudes and perceptions towards specific ideas or statements [28]. It has significant advantages in the fields of social science research, psychology, and market research, and is favoured for its simplicity, intuition, and ease of understanding. Each question is carefully designed and usually consists of five or seven levels of response options representing different levels of attitudes or opinions. These are "strongly agree (5)", "agree (4)", "neutral (3)", "disagree (2)" and "strongly agree (3)". " and "strongly disagree (1)". Respondents choose the degree to which these options most closely match their perceptions based on their true feelings. This scale not only captures the respondents' explicit attitudes, but also reflects their relative priorities on the issue, thus providing more comprehensive and nuanced information.

By using a Likert scale, this study can get a more accurate picture of the respondents' attitudes and perceptions towards the integration of IoT technology with fire evacuation plans for high-rise buildings [29]. This will help to gain insights into their acceptance of the new technology application, their assessment of the effectiveness of the programmed, and their feedback on any concerns or issues that may have arisen. The flexibility of the Likert scale allowed us to obtain more data on the cognitive and affective aspects of the respondents, which in turn provided more objective and comprehensive conclusions for the study.

Overall, the adoption of the Likert scale will provide an efficient and accurate way of data collection for our study, help us to better understand the perspectives and attitudes towards the integration of IoT technology with fire evacuation plans for high-rise buildings, and provide useful references and guidance for future fire safety management.

The sources of the questionnaires are shown in Table 2 and the specific questionnaires can be found in Appendix 1.

Table 2
Items Source

Number	Theme	Literature Sources
1	In terms of fire escape from high-rise buildings, IoT technology can significantly improve the escape efficiency	[30,31]
2	Internet of Things (IoT) technology is more reliable than traditional fire protection systems for fire escape in high-rise buildings	[26,32]
3	Willingness to accept and use the application of IoT technology in fire evacuation of high-rise buildings	[33]
4	Internet of Things (IoT) technology in high-rise building fire escape is important to improve the efficiency of escape	[32]
5	How much time do you think it used to take on average to escape from a high-rise building fire	[34]
6	High-rise building management is supportive of the introduction of IoT technology	[35]

4. Findings and Discussion

4.1 Multiple linear regression analysis

The researcher collected 384 samples through questionnaires and obtained 138 valid questionnaires. The authors' study focused on the dependent variable "fire escape efficiency in high-rise buildings" as well as the independent variables "popularity of IoT technology" and "stakeholders' attitudes towards IoT technology". This study performed data analyses using multiple linear regression models to examine the association between the factors are studying (independent variables) and the outcome of interest (dependent variable). The specific results of the analyses have been presented in detail in Table 3.

Table 3
Linear regression analysis results

Linear regression analysis results (*n*=138)							
	Unstandardized coefficient		Standardized coefficient	*t*	*p*	Covariance Diagnostics	
	B	standard error	*Beta*			VIF	tolerance level
constant	0.684	0.253	-	2.704	0.008**	-	-
Penetration of IoT technologies	0.557	0.099	0.564	5.649	0.000**	2.5	0.401
Stakeholder attitudes towards IoT technologies	0.26	0.1	0.26	2.599	0.011*	2.5	0.401
R^2	0.612						
adapt R^2	0.604						
F	*F* (2,97) =76.652, *p*=0.000						

D-W 值	1.79
Dependent variable: escape efficiency	
* p<0.05 ** p<0.01	

From the above table, the popularity of IoT technology, stakeholders' attitude towards IoT technology is taken as the independent variable while the escape efficiency is taken as the dependent variable for the linear regression analysis, from the above table, the model equation is: escape efficiency = 0.684 + 0.557*popularity of IoT technology + 0.260*stakeholder's attitude towards IoT technology, and the R-squared value of the model is 0.612 implies that the penetration of IoT technology, stakeholders' attitude towards IoT technology explains 61.2% of the variation in escape efficiency. The F-test of the model found that the model passed the F-test (F=76.652, p=0.000<0.05), which means that the popularity of the IoT technology and at least one of the stakeholders' attitudes towards the IoT technology can have an impact on the escape efficiency. In addition, the test for the multiple covariance of the model found that the VIF values in the model are all less than 5, which means that there is no covariance problem; and the D-W values are around the number 2, thus indicating that there is no autocorrelation in the model, there is no correlation between the sample data and the model is better.

4.2 Analysis

The regression coefficient value of the popularity of IoT technology is 0.557 (t=5.649, p=0.000<0.01), which implies that the popularity of IoT technology will have a significant positive impact relationship on escape efficiency.

The regression coefficient value of stakeholders' attitude towards IoT technology is 0.260 (t=2.599, p=0.011<0.05), implying that stakeholders' attitude towards IoT technology will have a significant positive impact relationship on escape efficiency.

In conclusion, the analysis shows that the popularity of IoT technology, stakeholders' attitude towards IoT technology all have a significant positive effect on escape efficiency.

4.3 Modelling

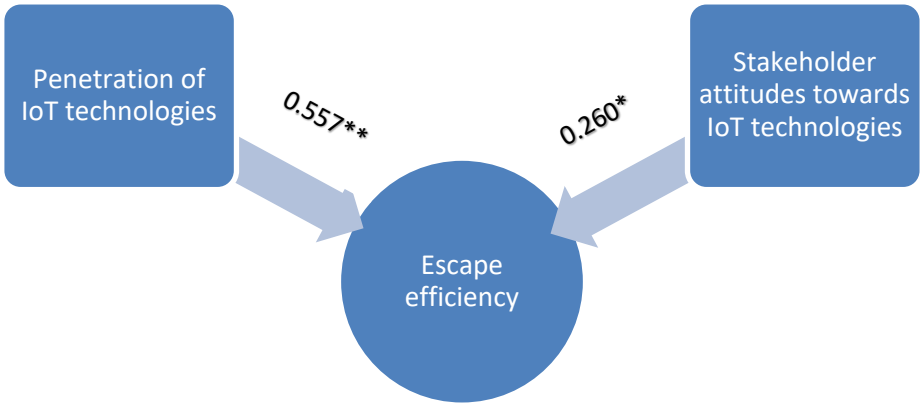

Fig. 2. Independent variable dependent model

As can be seen in Figure 2, a linear regression analysis has been carried out with the popularity of IoT technology, stakeholders' attitude towards IoT technology as independent variables and escape efficiency as dependent variable, and as can be seen in Table 4, the R-square value of the

model is 0.612, which means that the popularity of IoT technology, stakeholders' attitude towards IoT technology can explain 61.2% of the variation in escape efficiency.

Table 4
Model aggregation (intermediate process)

R	R^2	Adapt R^2	modelling error RMSE	DW value	AIC value	BIC value
0.783	0.612	0.604	0.921	1.790	273.341	281.156

4.4 Testing the regression model

As can be seen in Table 5, the F-test of the model was passed (F=76.652, p=0.000<0.05), i.e., it shows that the model construction is meaningful.

Table 5
ANOVA form (intermediate process)

	square sum	*df*	mean square	*F*	*p-value*
regression	134.076	2	67.038	76.652	0.000
residual	84.834	97	0.875		
aggregate	218.910	99			

4.5 Missing samples

The valid samples and the exclusion of invalid samples when the real enters the algorithmic model etc. are shown in Table 6. "Valid samples" in the table below refers to the total number of samples that have data on all items of analysis. If a sample has missing data on any of the analysis items (i.e. excluded invalid samples), that type of sample cannot be entered into the model for analysis and the model can only analyse valid samples.

Table 6
Summary of sample deficiencies

Sum	Sample size	Percentage
Active sample	138	35.9%
Exclusion of invalid samples	246	67.1%
Aggregate	384	100%

5. Discussion

5.1 Results of the discussion

In analyzing the results, it became clear that the findings were very much in line with meeting the initial expectations of the researchers, confirming the critical role of IoT technology in enhancing fire evacuation plans for high-rise buildings. This validation is consistent with the extensive literature review conducted [36]. Literature review highlights the positive impact of IoT technology on fire safety and evacuation plans for high-rise buildings [26]. However, the study also found unexpected results, demonstrating that IoT technology is more effective in specific areas of high-rise building fire evacuation compared to the broader coverage found in the literature review. Discrepancies between the findings of the study and the literature review may be attributed to other local factors such as social policies and people's security awareness [37]. A close review of the literature reveals many examples of the use of IoT technologies in fire evacuation planning, including smart sensing, data

interconnectivity, real-time monitoring, and the utilization of emergency exit markers [38]. While the results of this study may not cover all the strategies discussed in the literature, they emphasize the diversity of IoT technology applications in different regions and environments. As noted by earlier researchers in the literature review, the implementation of IoT technology has been shown to be advantageous at different stages. In the building design phase, IoT technology can simulate and analyze with different evacuation strategies.

5.2 Limitations

Although this study has achieved some results, there are still some limitations; the sample scope of this study may be limited to specific types of high-rise buildings, so the generalizability and applicability of the conclusions may be restricted. Due to limitations in time and resources, this study utilized a specific data collection method, which could potentially impact the comprehensiveness and accuracy of the data. The analysis is based on the current level of development of IoT technology, and the rapid advancement of IoT technology in the future may make the results of the study obsolete. In addition, fire escape from high-rise buildings involves numerous variables that are affected by a variety of factors such as building structure, fire size, and evacuation behaviours, and it is inevitable that this study was unable to comprehensively consider all factors. These limitations highlight the need for future research to expand the sample to cover a wider range of high-rise buildings in different regions and building ages. It is also recommended that field studies be conducted to utilize a more diverse and representative sample to enhance the validity and generalizability of the findings. In addition, field tests of IoT technologies in fire escape from high-rise buildings should be conducted in real-life scenarios, which can provide a more realistic assessment of their effectiveness and feasibility. Future research could pay more attention to the development trend of IoT technology to better apply and evaluate its advantages in fire escape from high-rise buildings. By acknowledging these limitations, future researchers can build on the findings of this paper by integrating multifactorial considerations, covering a broader scope, and employing multi-method data collection, which will contribute to a more comprehensive understanding of the efficiency of fire escape in high-rise buildings.

5.3 Suggestions for future research

There are limitations to the research methodology, scope, and direction of the research in this paper. However, these limitations provide opportunities for future research to expand and enhance our understanding of IoT technology in high-rise building fire evacuation. When it comes to possible future research directions, the following recommendations can be considered to further expand the field of research on the efficiency of fire escape from high-rise buildings and the application of IoT technology:

i. Integration of Internet of Things (IoT) technology with fire protection systems: Future research could concentrate on the seamless integration of IoT technology with conventional fire protection systems, aiming to create smarter and more efficient fire warning and evacuation programs. The focus of research could be on sensor networks, personnel location technology, automated control, and other areas, to achieve real-time response and automated processing within fire protection systems.
ii. Research on personnel evacuation behaviours: conduct in-depth research on personnel evacuation behaviours when fire occurs in high-rise buildings, including behavioural patterns, decision-making processes, and escape path selection. Combined with the data of the Internet

of Things technology, it can better optimize the evacuation plan, predict the trend of personnel flow, and improve the efficiency of evacuation.

iii. Simulation and Virtual Reality Technology Application: using simulation and virtual reality technology, study the fire escape scenarios of high-rise buildings and evaluate the effect of IoT technology in the virtual environment. This approach can provide a safe, economical, and practical test platform to avoid the impact on the real environment. These are some possible future research directions that will provide a broader research vision and innovation space for the improvement of fire escape efficiency in high-rise buildings and the expansion of the application of IoT technology. These research results will contribute more far-reaching significance to urban safety and residents' life.

6. Conclusions

Due to its complexity and unique architectural features, the fire evacuation accident rate of high-rise building fires is extremely high. With the goal of enhancing fire safety and efficiency in evacuation, this research endeavours to investigate the benefits of Internet of Things (IoT) technology in high-rise building fire escape scenarios and assess its practical impact on fire evacuation strategies. The findings of the study reveal that IoT technology exhibits remarkable advantages in facilitating fire evacuation procedures in high-rise buildings. With innovative features such as intelligent sensing, data interconnection and real-time monitoring, IoT technology greatly improves the efficiency of fire escape and significantly reduces the risk of casualties. IoT technology plays a crucial role in optimizing the fire evacuation process, from high to low floors and addressing complex building structures to ensuring accurate marking of emergency exits.

These encouraging research findings also bring valuable guidance. Based on the research findings, this study have made recommendations that this study hope will provide useful references for future fire escape planning and fire evacuation plans for high-rise buildings. Optimizing the emergency access routes within buildings, enhancing the application of IoT technology in fire protection systems, and increasing the awareness and acceptance of IoT technology among residents and employees are all necessary measures to achieve safer fire escapes.

Therefore, through the efforts of this study, have reason to believe that with the help of IoT technology, the efficiency of fire escape in high-rise buildings will be further improved in the future, and high-rise buildings will become safer places to live and work. This will be a great contribution to the construction of cities and the safety of people's lives, as well as providing strong support for disaster prevention and rescue efforts.

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