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UAV Application for Typhoon Damage Assessment in Construction Sites

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Abstract: The safety inspection capability of construction sites before typhoons could be improved using a UAV, which has a rapid identification capability. However, the main safety inspection items need construction experience and technical safety specifications. This study aimed to obtain the influencing factors of typhoon and their weight proportion through the knowledge of disaster theory and the analytic hierarchy process (AHP). The effectiveness of this method was verified by collecting and analyzing the field data at the construction site. A set of construction site early warning flows and disaster prevention and mitigation measures for typhoons are proposed. The results show that UAVs can be used as a tool in this scenario, helping to improve disaster prevention and enhancing the capability of construction site management to evaluate typhoon risk. The research provides a much-needed common ground for collecting and analyzing advances in UAVs and immersive technologies, as well as their influence on building projects. Furthermore, this article provides a new horizon for beginner researchers working on digitalized construction research.

Keywords: UAV; warning flow; disaster prevention; risk mitigation; security check; disaster theory

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1. Introduction

With the fast development of urbanization, the construction scale and output values are rising exponentially [1], but due to the complexity of construction projects, various risk factors are generated by frequent natural disasters such as typhoons [2]. The annual losses from typhoons are enormous, including but not limited to personnel safety accidents. At the present stage, the disaster prevention and reduction measures on construction sites do not efficiently lead to severe destruction. Conventional disaster management approaches have disadvantages such as low efficiency and poor effect, proven no longer suitable for complex construction management sites [3]. Typhoons can be decomposed into different indicators. Thus, the impact of each indicator of this natural disaster on construction can be conducted with in-depth theoretical research on disaster science [4]. The ability to mitigate typhoon damages can be improved by applying intelligent detection techniques such as Unmanned Aerial Vehicle (UAV) applications [5].

Natural disasters such as typhoons play damaging roles in human economic development [6–8], ecological civilization, and social stability [9]. A typhoon has two types of impacts, including physical impacts and social impacts. Physical impact includes visible human loss and economic damages, and social impacts include social order and psychological panic among human beings. The authors of [8–12] studied holistic assessments of typhoons and proposed the fragility analysis, including each physical element. The authors of [13] proposed a framework based on expert experience examining the preparedness and recovery phases of disaster management activities and processes of predictable disasters. However, the construction sector often fails to take adequate preventive measures for disasters such as typhoons leading to significant losses. The author of [14] proposed a

three-level image-based approach for disaster inspection on reinforced concrete bridges using deep learning with novel training strategies. The authors of [15] developed a model incorporating rainfall probability during a typhoon when evaluating construction projects related to climate adaptation to reduce infrastructure damages. The authors of [16] stressed the importance of social preparedness for flood loss mitigation based on early warning systems between the hydrological and social spheres, especially when technical forecasting and warning capabilities were limited.

UAVs used to be mainly implemented in the military field initially, and with the development of science and technology, UAVs began to be used for civilian use [17]. UAVs are widely used in geological prospecting, surveying, entertainment photography, and so on [12,18,19]. Due to the powerful maneuverability and the high-resolution image data acquisition function, scholars began to study the UAV applications in natural disaster prevention [20,21]; for example, [22] proposed a UAV-based method for emergency investigations on single geo-hazards. However, the use of drones in pre-disaster safety inspections on construction sites is still in its early stages [23]. This study aims to develop a pre-typhoon construction site warning and contingency treatment standard operational procedure (SOP) through a series of theoretical model development and construction site experiments. Various criteria of typhoon damage on construction sites were determined through qualitative and quantitative analysis. The effectiveness and feasibility of the developed SOP were verified through UAV experiments on an accurate construction site, the Xiamen Electronic City project. This study also proposed typhoon warning and response scenarios on construction sites.

2. Construction Sites and Natural Disasters

Natural disasters include disasters related to meteorological, geological, ecological, and environmental phenomena and disasters caused by biological agents. Each type of disaster can be further divided into several sub-disaster series [24]. For example, meteorological disasters can be divided into a rainstorm, typhoons, snow, ice, and other disasters. Each type of natural disaster may act as a disaster-causing factor in a construction area at the same time and produce a co-occurrence disaster chain [25]. The generation of typhoons may be accompanied by a rainstorm [26]. The simultaneous occurrence of these two leads to a sharp increase in the destructive power of disasters, forming an amplified effect. Meteorological disasters and geological disasters are the main culprits of severe property losses in construction sites.

In disaster science, the formation of a construction site disaster mainly consists of three parts: disaster-forming environment, disaster factors, and disaster-affected body [27]. The three parts are interconnected and interact with each other leading to the final losses. Relevant studies in disaster science indicate that a disaster is usually the result of the coupling of multiple factors [28]. The complex construction site is the central part of the disaster environment. The factors causing damage are relatively complex, divided into internal factors such as human factors in the construction site and external factors such as typhoons as the force majeure factors.

Moreover, the vulnerability of disaster-affected bodies, the risk of disaster-causing factors, and the exposure of disaster-affected bodies are widely used as indicators to quantify the theoretical model of disaster science [29]. Disaster prevention and reduction indicators are established and applied in relevant fields [30,31], and a theoretical model of the natural disaster is in Equation (1). The current study further optimized the applicable model based on construction site parameters as in Equation (2).

$$\text{Risk of Typhoon} = (\text{Danger} \times \text{Vulnerability} \times \text{Exposedness}) / (\text{Disaster-prevention Capability} \times \text{Disaster-mitigation Capability}) \quad (1)$$

$$\text{Damaged Degree to Construction Sites from Typhoon} = (\text{Danger of Typhoon} \times \text{Exposure to Construction Site} \times \text{Fragility of Construction}) / (\text{Disaster-prevention Capability of Management Personnel} \times \text{Disaster-mitigation Capability of Management Personnel}) \quad (2)$$

The establishment of the theoretical model of the construction site under typhoons in Equation (2) enabled the analytic hierarchy process (AHP) for quantitative analysis in this study. In order to make better use of the theoretical model, various parameters from related kinds of literature were analyzed in the disaster chain to ensure the systematic, typical, scientific, and quantifiable rationality of the indicator selection [32]. After a comprehensive content analysis, the parameters in construction sites under natural disasters were classified into five groups, namely risk, exposure, vulnerability, the capability of disaster prevention, and the capability of disaster mitigation. For determining the detailed impact indicators of the five groups, 35 specific indicators were categorized in Table 1.

Table 1. Risk index decomposition for construction sites under typhoon.

Target Layer	Criterion Layer	Factor Layer
The degree of risk related to construction sites under typhoon (A)	Risk (B1)	Typhoon intensity (C1) Annual frequency of typhoons(C2) Maximum daily precipitation (C3) Mean annual precipitation (C4) Regional elevation (C5) Regional vegetation coverage rate (C6) Width of drainage channels in respective districts (C7) The integrity of drainage channels in respective districts (C8)
The degree of risk related to construction sites under typhoon (A)	Exposure (B2)	Number of on-site construction management personnel (C9) Number of workers in each construction team (C10) Construction materials (C11) Mechanical equipment matching (C12) Tower crane (C13) Scaffold (C14) traffic conveyance (C15) Staff office accommodation (C16)
The degree of risk related to construction sites under typhoon (A)	Vulnerability (B3)	Vulnerability of construction in progress (C17) Vulnerability of large mechanism(C18) Vulnerability of construction materials (C19) Worker vulnerability index (C20)
The degree of risk related to construction sites under typhoon (A)	Capability of disaster prevention (B4)	Predictive accuracy of Met Office (C21) Number of monitoring sites (C22) Number of site investigations (C23) Speed of communication (C24) Number of emergency personnel (C25) Level of emergency equipment(C26) Evaluation index of emergency management (C27) Medical professional (C28) Rationality of organizational structure(C29) Level of the project manager (C30)
The degree of risk related to construction sites under typhoon (A)	The capability of disaster mitigation (B5)	Share of project investment devoted to security risk (C31) The capability of risk response (C32) The executive ability of site personnel (C33) Level of the project manager (C34) Requirements for goal achievement (C35)

As the ecological environment is being destroyed, the risk of global natural disasters rises sharply. Natural disasters include earthquakes, forest fires, typhoons and rainstorms, mud-rock flows, blizzards, landslides, etc. The prevention and mitigation of natural disasters have attracted the attention of scientific researchers in various fields such as tourism [33], campus security [29], fire department [34], energy [23], and municipal councils [22,27], who reviewed power system risk identification combined with typhoon scenario. They provided a new research idea about using appropriate data analysis methods to identify risks and faults, simulate fault propagation, and develop disaster prevention

and mitigation strategies. The authors of [29] used the Analytic Hierarchy Process method and k-means Clustering Algorithm to identify the factors, including natural and human activities, landslide–debris flow hazards, environmental susceptibility, and exposure. Researchers pay attention to the disaster-forming factors, environmental susceptibility, and exposure to assess the risks of natural disasters.

In recent years, construction site safety accidents frequently resulted in heavy losses to construction personnel, the economy, and buildings. The construction industry is susceptible to extreme weather events due to most of its activities being conducted by construction workers outdoors [35]. Ref. [36] revealed that the type of accident with the highest risk score is "falling objects", while the leading cause is excessive winds on the project site. Natural disasters such as typhoons and rainstorms can produce strong winds and cause damage to incomplete construction. A super typhoon can blow down under-construction buildings or even cause accidents when a construction site is not well protected. The destructive power of natural disasters on buildings has drawn wide attention from researchers. Ref. [37] developed a conceptual weather environmental forecasting system (CWEFS) that can be used to identify potential safety risks of structures under construction through a typhoon wind velocity model and structure reference load simulation. Ref. [38] investigated wind pressure characteristics on the roof of a low-rise building during typhoon landfalls to reduce windstorm damage to residential buildings. Ref. [39] researched wind effects on a 420 m-tall building during typhoons by investigating wind effects by field measurements and wind tunnel testing. Ref. [40] proposed a PSO-based seepage safety monitoring model that simulates the sudden increase in the piezometric level induced by short-duration heavy rainfall and the possible historical extreme reservoir water level typhoon problems regarding the safe operation of hydraulic structures. Their research expounded on the function form of the typhoon on different buildings and theoretically analyzed the key to structural safety and protection. In contrast, some other researchers pay attention to the risk assessment of buildings under natural disasters.

Ref. [41] used the analytic hierarchy process to compare uncertainty estimates in pairs and rank risk likelihood occurrence, specifically in construction projects during construction phases. The risk assessment and management process usually include establishing the environment, identifying risks, analyzing and evaluating risks, obtaining risk warnings, and making decisions [28]. Among them, risk identification and assessment are a significant part of risk management and the primary support for decision making [42]. The purpose of disaster identification is to identify environment-related hazards in the area of risk assessment. This requires a systematic review of all to determine whether they might pose a threat to the construction. Natural forces cause natural disasters, so the risk of each hazard is checked, and some possible scenarios after the disaster. The vulnerability of the construction site to the disaster is simulated in the risk assessment process. Ref. [43] created a conceptual model for natural disaster risk assessment, including disaster analysis, vulnerability assessment, and risk. Nevertheless, there was still a significant lack of studies on the combination between hazard analysis and vulnerability assessment. Ref. [44] developed an integrated web-based GIS platform for the risk identification and safe management of complex structural areas exposed to intense wind actions. Their research demonstrated the platform's applicability to construction sites that can implement wind effects on structures, infrastructures, and complex territorial systems.

We should be aware of safety precautions before the occurrence of natural disasters on the construction site for safety quality inspection and risk identification. Ref. [45] developed a safety performance index assessment software tool with the incorporation of fuzzy set theory into structural equation modeling to assess the safety performance of construction sites. The traditional inspection and identification method is that the Health and Safety Coordinator (HSC) figure uses the conventional inspection equipment and professional experience to check the construction site of the project seriatim [46], which has the disadvantages of long inspection time and low efficiency. With the advent of UAVs and their peculiar advantages, different research directions have been pointed out for the

construction industry, leading to many applications and innovative developments in safety inspection and risk identification on construction sites [47]. However, the safety checks before natural disasters using UAVs on construction sites are still preliminary. Ref. [48] studied the application of UAVs for the safety inspection used in the scene of disaster detection and warning of unsafe conditions in the prevention of safety accidents. They suggested future research directions about understanding how this technology can be incorporated into the construction management task and its potential impact on preventing or mitigating unsafe working conditions. In order to address the current shortcoming, this study carried out the safety inspection of construction sites before the natural disaster, combining the advantages of UAV safety inspection and the characteristics of disaster factors, building vulnerability, and exposure in risk management, in addition, to improving the ability of safety inspection and providing support for the reduction in accidents related to natural disasters on construction sites through the establishment of UAV visual operation platform and post-image technology.

3. Research Methods and Procedures

Due to the complexity of construction sites, it was difficult for construction managers to forecast typhoon damages effectively. Therefore, a detailed analysis of construction sites in reference to relevant theoretical disaster science, including disaster-forming environment, disaster-causing factors, and disaster-affected bodies, was conducted to decompose the disaster chain in the construction site and establish an Analytic hierarchy process (AHP) model for the typhoon criteria. Various criteria of typhoon damage on construction sites were determined through qualitative and quantitative analysis. The effectiveness and feasibility of the developed SOP were verified through UAV experiments on an accurate construction site, the Xiamen Electronic City project.

3.1. Analytic Hierarchy Process

Analytic hierarchy process (AHP), as a hierarchical weight analysis method for multi-objective evaluation, stratified the targets to form multiple target layers and compared the indicators in each target layer to construct a comparison matrix. By calculating the importance of each indicator layer relative to the previous one, the relative weights of all indicators were obtained. AHP complemented the qualitative method and provided a more rigorous connection to the research from a quantitative perspective [49,50].

3.1.1. Defining the Structure Model and Constructing the Pair Comparison Matrix

Each sub-target established by the disaster chain was decomposed to obtain the complete structure model. The pairwise comparisons of different factors to determine their relative importance formed the judgment matrix, where the comparison result was between index i and index j. The judgment matrix used the following relationship in Equation (3).

$$a_{ij} = \frac{1}{a_{ji}} \tag{3}$$

The weight of the judgment matrix is shown in Table 2.

Table 2. Weights of judgment matrix.

Weights	Implication
1	The two indicators are of equal importance
3	One is slightly more important than the other
5	One is obviously more important than the other
7	One is mightily more important than the other
9	One is extremely more important than the other
2,4,6,8	The intermediate value of the above two adjacent
reciprocal	The comparison of factor i to factor j is calculated as a_{ij} the comparison of factor j to factor i is calculated as a_{ji} $a_{ij} = \frac{1}{a_{ji}}$

The structure of the matrix is shown in Table 3.

Table 3. Structure of the judgment matrix.

A_K	B_1	B_2	...	B_n
B_1	b_{11}	b_{12}	...	b_{1n}
B_2	b_{21}	b_{22}	...	b_{2n}
...	...	...	...	...
B_n	b_{n1}	b_{n2}	...	b_{nn}

3.1.2. Hierarchy and the Consistence Check

The priority weights of hierarchy elements can be determined, and the consistency check of the comparison matrix can be performed by using AHP. After determining the relative importance of the index of the next layer relative to the index of the previous layer and then solving the eigenvector with the constructed matrix, the applied formula is as follows in Equation (4).

$$\mathrm{AW} = \lambda_{\max} \cdot W \tag{4}$$

where $\lambda_{\max}$ is the largest eigenvalue of matrix A; W is the relative weight of each index layer element.

Then, the judgment matrix constructed is ordered in a consistent check and rank shown in Equation (5).

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{5}$$

where the smaller the value of CI, the higher the consistency of the judgment matrix. When CI = 0, the matrix has complete consistency; the larger the value of CI, the worse the consistency. In order to make the constructed matrix have satisfactory consistency, we need to introduce the random consistency index RI shown in Table 4.

Table 4. The value set of RI.

Matrix Scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

When CR meets the condition CR < 0.10 by calculated in Equation (6), it shows that the judgment matrix we constructed conforms to the consistency check.

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{6}$$

3.1.3. Method Execution and Result Presentation

We sorted out and summarized the matrix diagram of the importance coefficient between different targets and target objects in the model by investigating the construction site and reading and summarizing the related literature [51]. The importance coefficient matrix of the Criterion layer factor is shown in Table 5. Then, we used Matlab to realize the quantitative calculation of AHP and carried out the consistency test to judge. The Matlab code is shown in Table 6. The weights of the quantitative calculation of the Criterion layer factors are shown in Table 7, and the weights and consistency indicators of the quantitative calculation of the Factor layer factors are shown in Table 8.

Table 5. The judgment matrix for A and B.

A/B_{ij}	B1	B2	B3	B4	B5
B1	1	3	3	2	4
B2	1/3	1	2	1/3	3
B3	1/3	1/2	1	1/2	2
B4	1/2	3	2	1	2
B5	1/4	1/3	1/2	1/2	1

Table 6. Matlab language code.

Class	Code of Part
consistency check of AHP	function [Q] = AHP(A) % Import matrix A [n,m] = size(A);% Check for consistency for i = 1:n,for j = 1:n if B(i,j)*B(j,i)~ = 1, fprintf('i = %d,j = %d,B(i,j) = %d,B(j,i) = %d\n',i,j,B(i,j),B(j,i)) % Find the eigenvalue eigenvector and find the eigenvector corresponding to the maximum eigenvalue [V,D] = eig(A);tz = max(B);tzz = max(tz); c1 = find(B(1,:) = = max(tz));tzx = V(:,c1);quan = zeros(n,1); for i = 1:n, quan(i,1) = tzx(i,1)/sum(tzx); end % consistency check CI = (tzz − n)/(n − 1); RI = [0,0,0.58,0.9,1.12,1.24,1.32,1.41,1.45,1.49,1.52,1.54,1.56,1.58,1.59]; % Determine whether it passes the consistency check CR = CI/RI(1,n); if CR > =0.1, fprintf('fail the condition of the consistency check\n'); else, fprintf('meet the condition of consistency check \n');

Table 7. The weight distribution for A and B.

Weight Distribution					Total
B1	B2	B3	B4	B5	
0.3902	0.1615	0.1167	0.2524	0.0792	1
λ_{max}: 5.2437		CI = 0.0609	CR = 0.0544 < 0.1, meet the condition of consistency check		

3.2. System Dynamics Modelling

System Dynamics is a theoretical method to further study the whole system by analyzing the feedback relationship among various system variables. The correlation degree among each variable and its impact on the whole system can be analyzed quantitatively by System Dynamics. Previously, the impact of the typhoon on construction sites was analyzed using relevant theories of disaster science. The possible impact of each disaster on construction sites in the disaster chain of typhoons and rainstorms was determined, and AHP obtained the index weight. Using system dynamics could improve the quality of quantitative analysis in this paper and explain the impact of the typhoon on construction sites more scientifically [52]. We used system dynamics to divide the impact of the typhoon on construction sites into three crucial factors: the disaster-forming environment, the disaster-causing factor, and the disaster-affected body; Figure 1 shows the overall mechanism of the site system model under natural disasters. We established the system dynamics model with VENSIM, as shown in Figures 2–4:

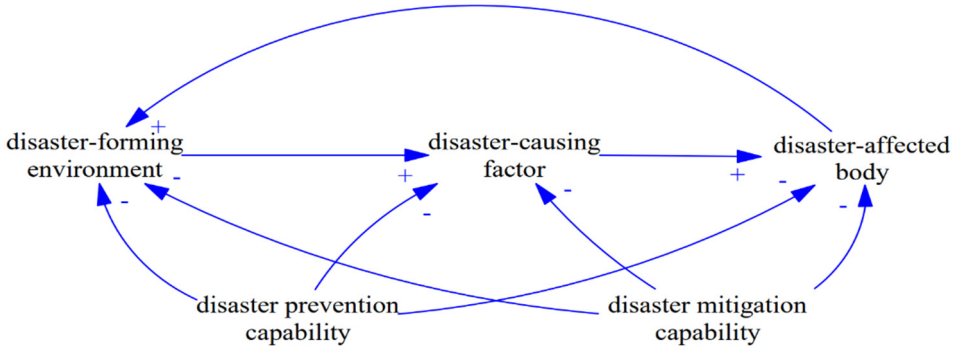


Figure 1. Overall mechanism of site system model under natural disasters.

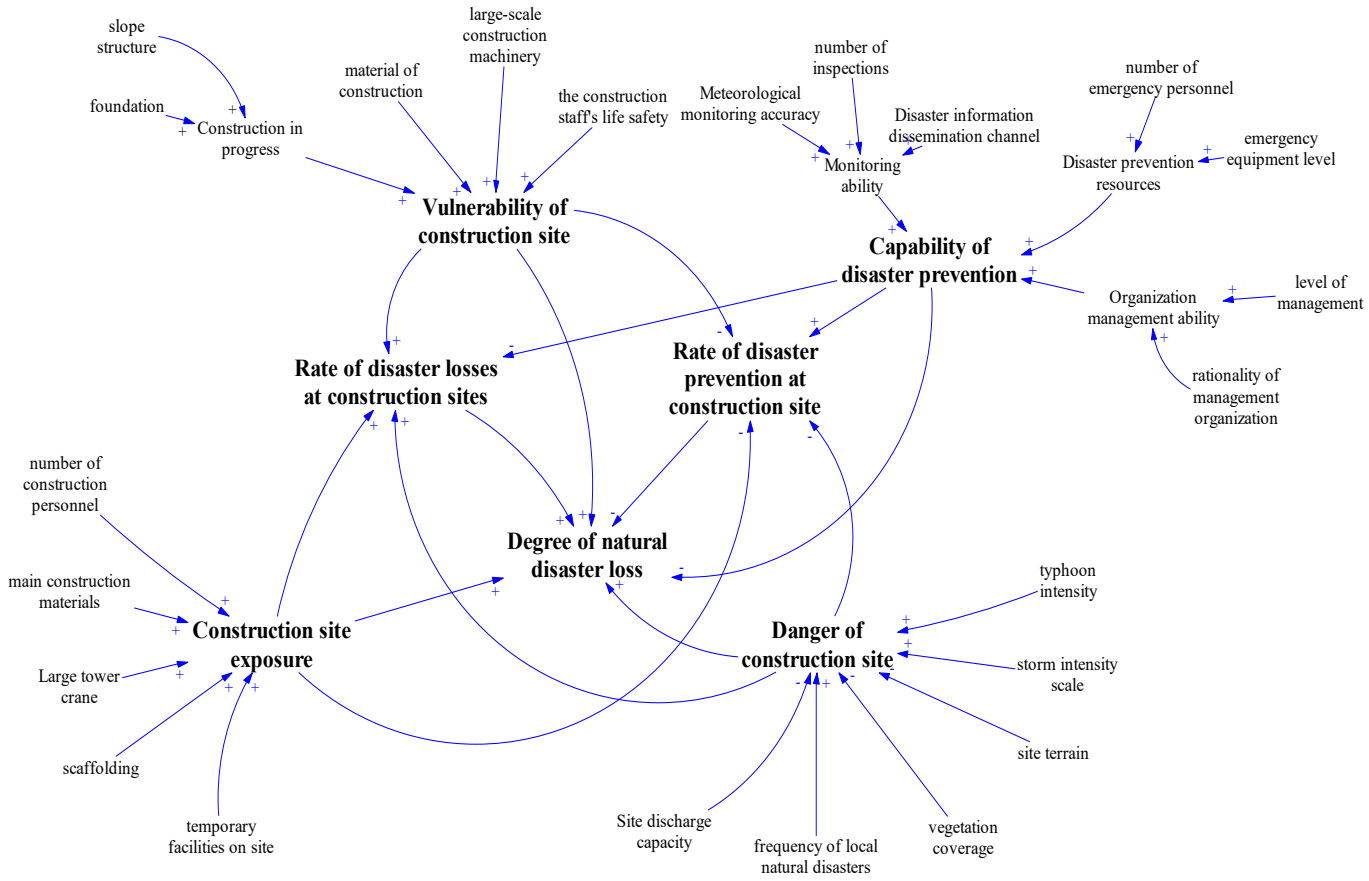


Figure 2. Causal analysis of construction site systems under typhoon.

Table 8. The weight distribution for B and C.

Weight Distribution							
B1\C1-C8							
C1	C2	C3	C4	C5	C6	C7	C8
0.3297	0.1472	0.2378	0.1022	0.0292	0.0339	0.0689	0.0512
λ_{max}: 8.3379			CI = 0.0483	CR = 0.0342 < 0.1, meet the condition of consistency check			
B2\C9-C16							
C9	C10	C11	C12	C13	C14	C15	C16
0.3244	0.2396	0.1099	0.0313	0.1285	0.0524	0.0806	0.0334
λ_{max}: 8.3204			CI = 0.0458	CR = 0.0325 < 0.1, meet the condition of consistency check			
B3\C17-C20							
C17		C18		C19		C20	
0.2811		0.1172		0.0705		0.5311	
λ_{max}: 4.1349		CI = 0.0450		CR = 0.0510 < 0.1, meet the condition of consistency check			
B4\C21-C30							
C21	C22	C23	C24	C25	C26	C27	C28	C29	C30
0.2461	0.0337	0.0518	0.0279	0.1878	0.1502	0.1026	0.0758	0.0679	0.0562
λ_{max}: 10.8533			CI = 0.0984		CR = 0.0636 < 0.1, meet the condition of consistency check				
B5\C31-C35							
C31		C32	C33	C34		C35	
0.2794		0.0830	0.1268	0.0643		0.4466	
λ_{max}: 5.2334			CI = 0.0583	CR = 0.0521 < 0.1, meet the condition of consistency check			

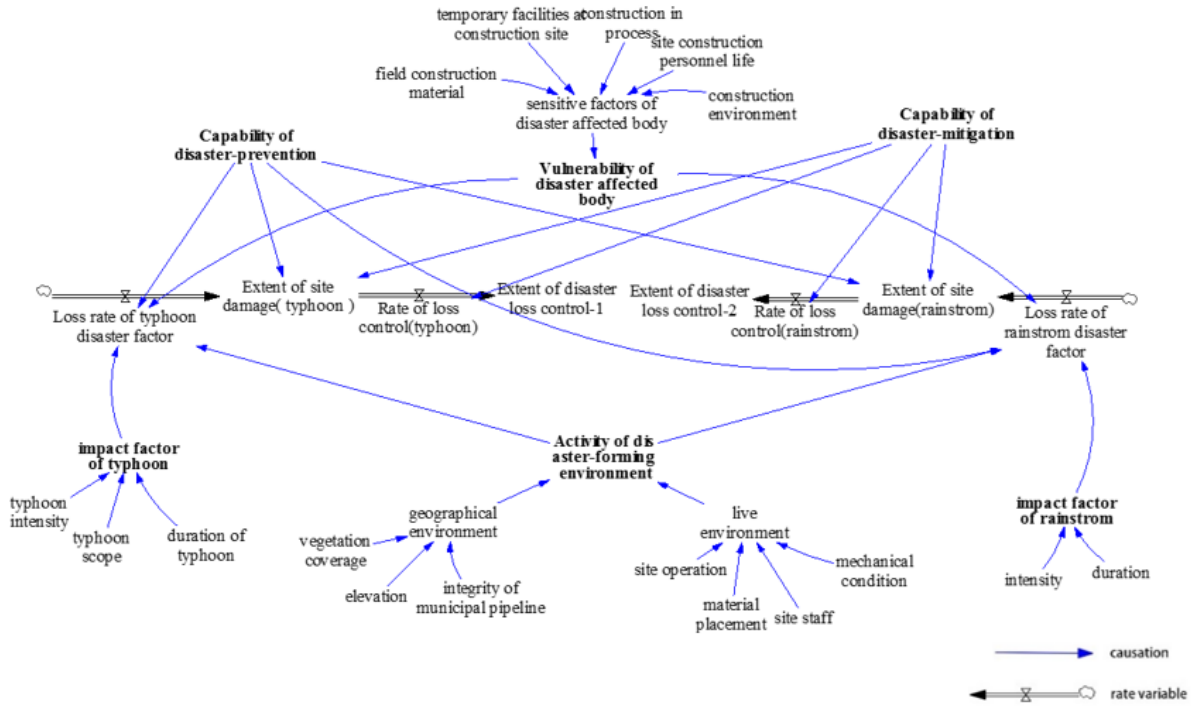


Figure 3. A flow diagram of a disaster system at a construction site under disasters.



Figure 4. Xiamen Electronic City project under construction.

4. Case Study and Process Design

4.1. Image Collection at the Construction Site

In this study, the Xiamen Electronic City project under construction was used as the case to collect images of the construction site. Xiamen Electronic City· International Innovation Center project is located in Jimei District, Xiamen City, Fujian, China, with a total area of 103,200 m^2 and a total construction area of about 570,000 m^2 (as shown in Figure 4). In this study, the construction risk analysis was carried out by building 3D and 2D models of the construction site, and the real-time image data acquisition of the construction site was carried out by UAV to verify the feasibility of the plan. The experiment used the DJI PHANTOM4 PRO V2.0. The specific parameters of the UAV and its load sensor are shown in Table 9. The point cloud model of the construction site was established based on the site image captured by the UAV. The pixel position information on the image of the construction site could be transformed into the position information of the construction site surface so that the point cloud model of the construction site could be established in reverse.

Table 9. Main parameters of UAV and payload sensor.

Aircraft		**Vision Sensing System**	
Weight	1375 g	Visual system	Front, Back, and Lower Vision Systems
Maximum ascent speed	Sport mode: 6 m/s Position mode: 5 m/s	Measurement frequency	Front: 10 HZ Back: 10 HZ Lower: 20 HZ
Maximum horizontal speed	Sport mode: 72 km/h Attitude Mode: 58 km/h Position mode: 50 km/h	Use environment	Textured surfaces, Adequate lighting (>15 lux)
Maximum altitude speed	6000 m	**Camera**	
Maximum withstand wind speed	10 m/s	Image sensor	1 in CMOS, Effective Pixels 20 million
Maximum flight time	30 min	**PTZ**	
Working temperature	0 °C–40 °C	Stable system	3 axes
Satellite positioning module	GPS/GLONASS	Controllable rotation range	Pitch: −90°~+30°
Infrared Perception System		**APP image transfer**	
Obstacle perception range	0.2–7 m	Mobile devices	DJI go4
Measurement frequency	10 HZ	Real-time image transfer	720P@30fps 1080@30fps

The weather on the experimental date was sunny, and the wind was less than level 4. In this experiment, the flight altitude of the UAV was set to 120 m, and the resolution of the converted image was guaranteed to meet the subsequent identification and detection work during the flight shooting at a speed of 2 m/s. Refer to the pix4d manual for general image acquisition mode requirements, and use regular grid mode to acquire images with at least 75% frontal overlap and 60% side overlap. The camera was kept at a constant height above the subject as much as possible. The images of the construction site captured by the UAV were then sorted, and the size of the obtained image was finally determined to be 1920*1088 through image conversion and screening, and the image acquisition result is shown in Figure 5.



Figure 5. The image of the construction site collected by UAV.

4.2. Three-Dimensional Modeling at the Construction Site

Pix4dmapper is an aerial survey software developed by a Swiss company. It is used to process images taken by UAVs. It has the advantages of high professional precision and automatic processing. It can automatically correct the camera and obtain high-precision 3D point cloud data and enables fast image processing. Therefore, pix4dmapper software was used for UAV image processing to achieve the rapid 3D model establishment of construction sites. In the pix4d software, the process of processing the UAV image to obtain the point cloud model is shown in Figure 6.

Firstly, the filtered image data were imported, including images taken by the UAV and POS data files. The POS data file contained the heading angle, pitch angle, roll angle, and the longitude, latitude, and elevation of the pictures taken during the flight operation of the UAV. The image path of the UAV was automatically generated after the image data were input. The input and output coordinate system was selected; this experiment used the CGCS2000 default coordinate system. Through the localization processing of image data, according to the collected 2D image data, the required 3D point cloud data of the construction site were synthesized by the principle of aerial triangulation photography of unmanned aerial vehicles.

Then, for point cloud and texturing, the photo location was displayed in green, indicating that the location information was correct, and the processing operation was started. The processing of point cloud data could be divided into three parts: point cloud synthesis, preprocessing, and segmentation. The first step was to synthesize the 3D point cloud. The imported images were aligned to generate sparse point clouds and calibrate the sparse point clouds through optimization. In order to perform point cloud segmentation later,

upsampling was used to encrypt the point cloud data to meet the design requirements of processing. The second step was point cloud preprocessing. The point cloud was downsampled by the methods of through filtering and voxel grid filtering, and the interference information and noise points in the point cloud data were filtered. The third step was point cloud classification and segmentation. The construction site scene of the construction site was complex, and the amount of point cloud data was large. In this study, the random sampling consistency segmentation algorithm was used to classify and segment the point cloud data, and the distance threshold parameter was set to 1.

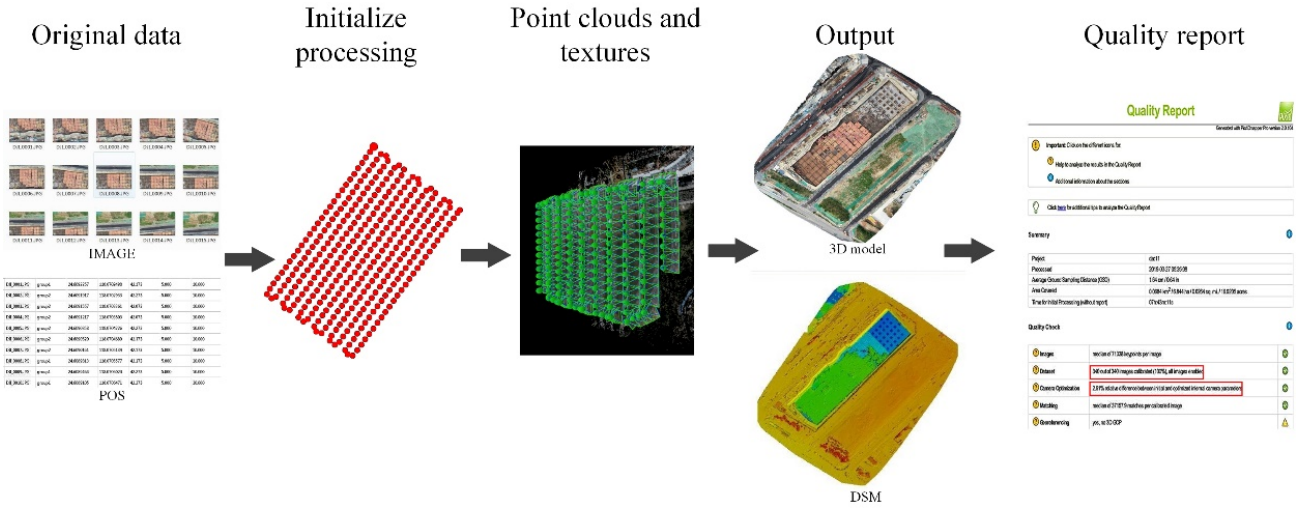
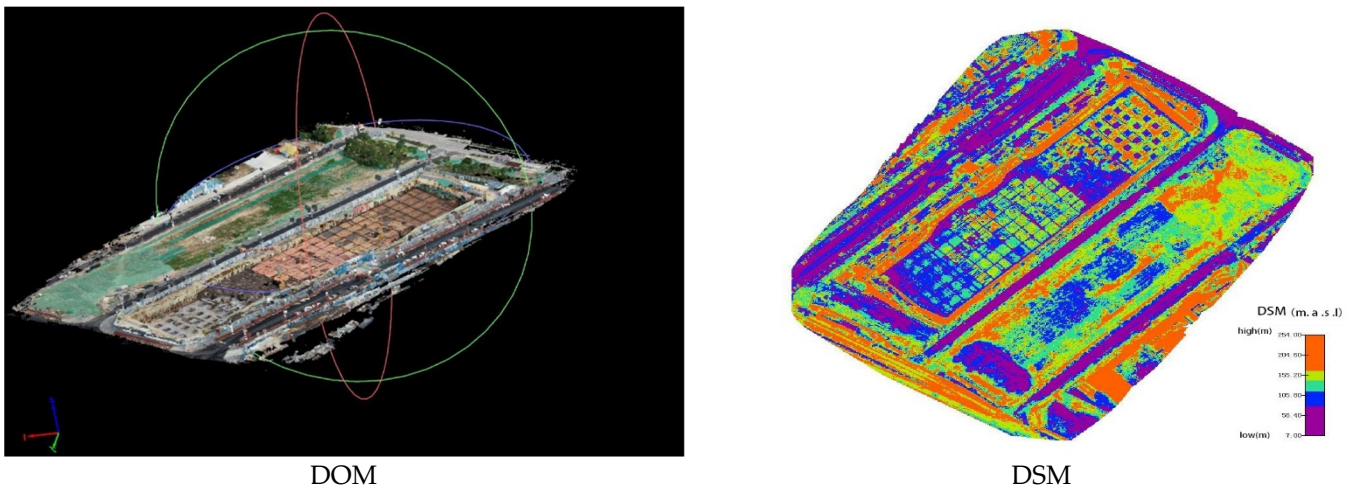


Figure 6. Pix4D mapper UAV image processing flow.

Finally, the output model results and quality report were obtained. Figure 7 shows the final generated digital orthophoto map (DOM) and digital surface model (DSM). The DOM could visually see the situation of the entire construction site, and the DSM image could digitally express the elevation of the construction site, where the blue part represented the lower area and the red part represented the higher elevation area. The quality report played a feedback role in the process of point cloud processing and model establishment, made targeted solutions to those that were not qualified in the quality report, and finally obtained a qualified quality report. The 3D model was not much different from the live pictures, and the quality report showed that the image calibration was 100% with all images enabled. The deviation between the internal and optimized camera parameters was 2.61%, the average ground sampling distance was 1.64 cm, and the coverage area was 68,400 m^2.



DOM DSM

Figure 7. The image of the digital orthophoto map (DOM) and digital surface model (DSM).

4.3. Monomer Modeling

According to the pix4d 3D modeling results, although the established 3D model of the construction site can visually observe the entire layout of the site, the accuracy of the details is low, which is not conducive to the development of site risk investigation. However, Smart3D software can carry out some point cloud models, monomers, and visual data. Due to the limitation, the output model of UAV oblique photography automatic modeling is an overall model, which cannot be implemented for selecting specific building objects and querying spatial information and other attribute information. We needed to monetize the model so that the data could be managed, not just viewed. Monomer modeling is to assign a single attribute to a single model in the model scene so that it can be observed and managed separately. The risk management of the construction site needs to check the various facilities on the construction site one by one, so individual modeling is an effective tool for project managers to carry out risk management. In this study, the slanted model was cut and singulated according to the needs of model management and the structure of the building itself so as to separate it from the physical structure and achieve singulation.

The first was the establishment of the model scene. The 3D model was constructed by the Context Capture modeling software, and the spatial data were loaded. The coordinate system of the model itself adopted the World Geodetic System (WGS84) geographic coordinate system. The model had not only high-precision geographic latitude and longitude coordinates but also had precise elevation coordinates. The case of the Xiamen campus of Huaqiao University was taken as an example of building a 3D model. Figure 8 shows the building process of the library's 3D point cloud model. Firstly, point cloud registration and noise filtering were performed, then point cloud classification was performed, and finally, point cloud model rendering was performed. The final 3D model was not much different from the actual building, so the model establishment had high accuracy.

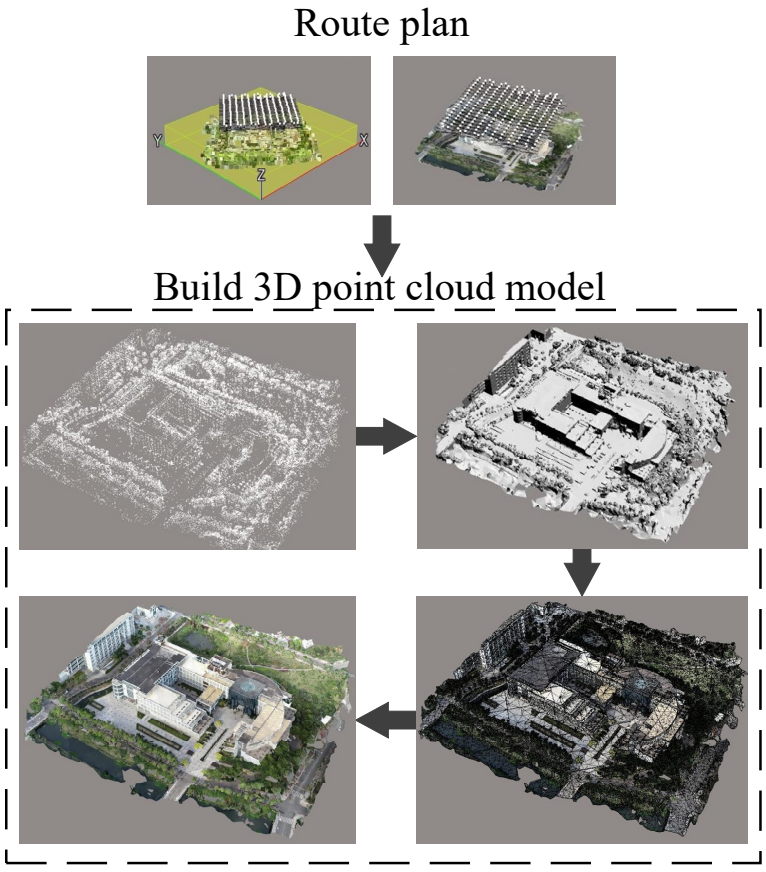


Figure 8. Building process of the library's 3D point cloud model.

Then, the monomer was modeled. The singulation is to use the vector surfaces corresponding to the buildings, roads, trees, etc., in the built 3D model to cut the oblique photographic model. Considering that the study used UAV photography for construction site risk visualization management, the method of dynamic vector surface superposition was used based on the system platform to achieve model singulation. The matching 2D vector faces were loaded into the same scene as the oblique photographic model. When rendering model data, the vector surface was stuck to the surface of the inclined model object, and then the color and transparency of the vector surface were set to achieve the effect that the features can be individually selected. The Smart3D Viewer module was used to collect two-dimensional vector coordinates for the single building to be realized. Through Polygon Hierarchy, the collected coordinates were used to construct the vector polygon to complete the geometry. For model transparency, highlighting was performed by adjusting material and classification type.

Rapidity and accuracy are advantages in earthmoving measurement by the 3D model, compared with the traditional earthmoving technology. Figure 9 shows a volume measurement using smart3D software. The left property bar shows the values of "cut/fill", "fill", and "sampling distance", which corresponds to the amount of "net cut/fill", "fill", and "cut". The traditional earthwork method has a large amount of calculation, low precision, and low efficiency. However, the foundation pit collapse caused by heavy rain and flood on the construction site needs to be dealt with as soon as possible. The use of 3D modeling software, with the broad prospect of use, can realize fast and accurate calculations to solve the problem of safety inspection before a natural disaster.

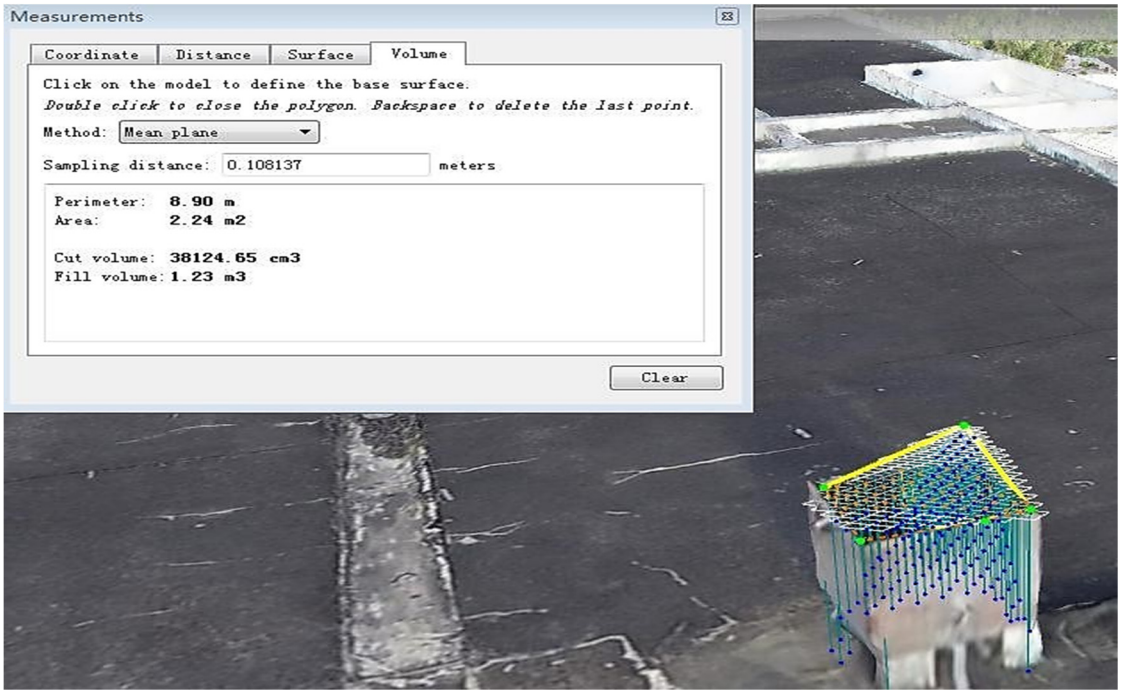


Figure 9. Application of volume measurement.

4.4. Number Identification

Three-dimensional modeling and related fundamental data analysis were carried out by acquiring the photo data of the construction site by UAV. However, the digital modeling function of UAVs cannot meet the requirement of disaster prevention and reduction work in a typhoon. Therefore, it is necessary to use photos for another aspect of analysis, such as using the function "volume measurement" in the pix4d to measure the earthwork volumes in the photos. If the calculated value exceeded the safety value in the specification, the construction teams were arranged to transfer the earthwork as soon as possible. Because

typhoons and other typhoons have the characteristics of strong wind and strong destructive power, we had to check potential safety hazards on the slope and the peripheral structure somewhere. We carried out the work of crack identification found at a slope on a construction site, as shown in Figure 10. By combining the Sobel algorithm and Prewitt algorithm in Matlab language, the image feature points of the cracks were picked up to improve more accurate hidden trouble information for subsequent work arrangement.

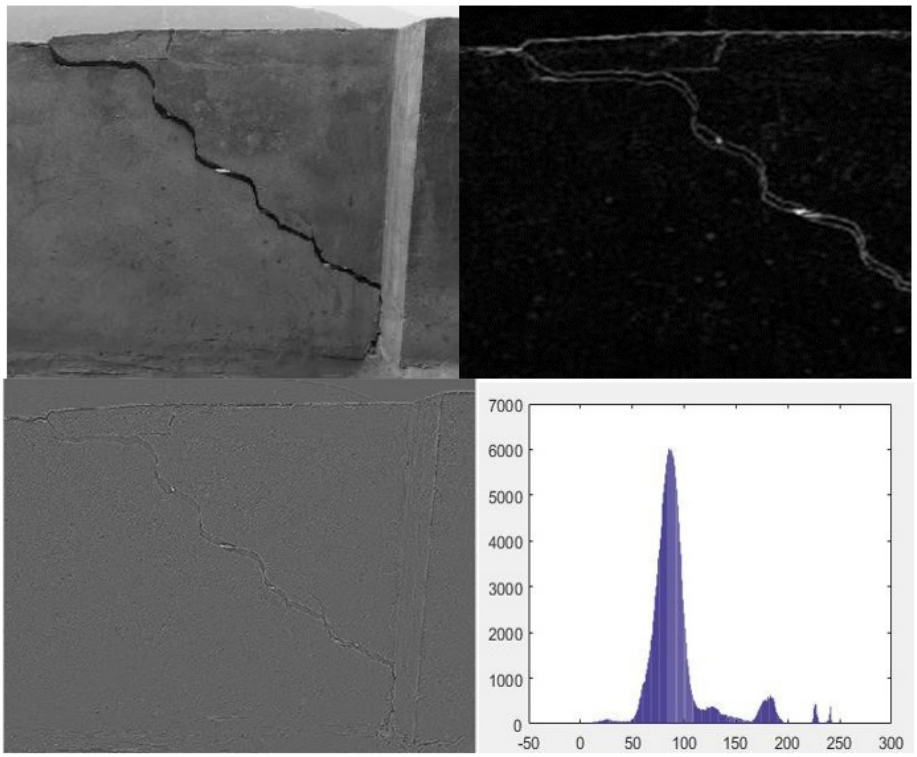


Figure 10. Different forms of crack identification characteristics (Original image, Sobel algorithm, Prewitt algorithm).

Typhoons are often accompanied by heavy rainfall, and the typhoon-rainstorm disaster chain brings strong destructive power to construction sites, which have low disaster prevention capacity. Our investigation found that many tower cranes collapsed under the typhoon, primarily due to hidden trouble in the connection. Meanwhile, there is also the potential for dangerous chain reactions. Such typhoons that blow down the large tower cranes may squash buildings or cause employee safety accidents in return. Therefore, we collected several groups of hidden safety information at the construction site of the project. In Figure 11, it is shown that corrosion and loosening exist in the screws from standard joints. In Figure 12, we found that the derailment of wire rope was caused by the inactivation of the anti-disengaging device.



Figure 11. Corrosion and loosening.

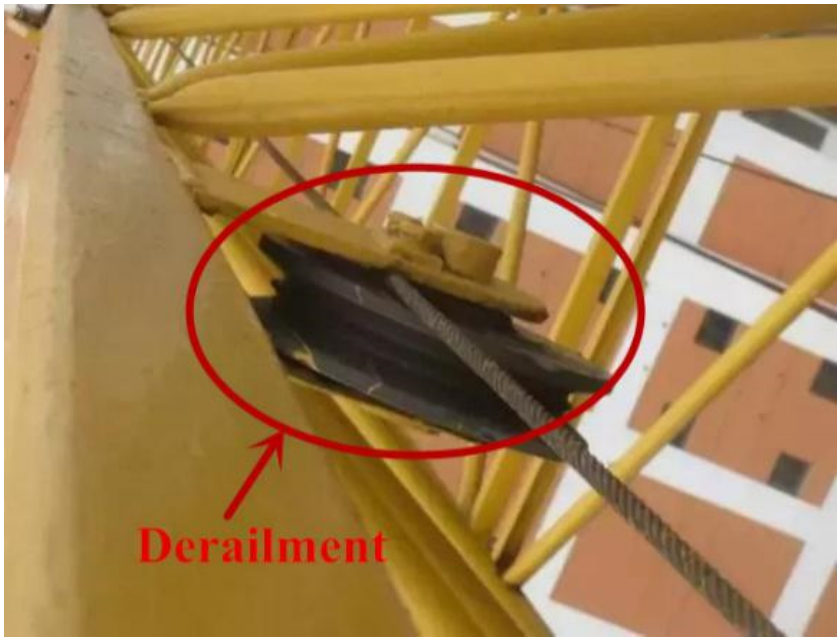


Figure 12. Derailment of wire rope.

The stability of large machinery, especially construction machinery such as tower cranes and scaffolds, affects the safety of construction sites. The time left for construction programs to carry out disaster prevention work is minimal when a typhoon strikes. Therefore, we can use the mobility of UAVs to identify dangerous areas at some structural joints. Safety inspection can be completed in a short time, and reinforcement warnings can be made for weak positions. Therefore, for these safety risks that do not conform to the relevant safety standards, management personnel can reduce risk and loss by accurately carrying out targeted disaster prevention and prevention.

5. Discussion

According to the investigation and assessment of the risk before natural disasters, it was found that the impact of natural disasters on the construction site was caused by

multiple factors and multiple nodes. For example, a typhoon disaster will blow down the tower crane, whose crane will further lead to the destruction of construction progress or squash other large machinery. It may stop at this point in the disaster timeline or continue to create a chain of disasters. Through case demonstration, it is not difficult to find that if we can take measures in the first part of the typhoon's impact on the tower crane, we can significantly reduce the possibility of the subsequent disaster, which is the "broken chain" theory to be researched in this paper. Relevant theoretical studies are shown in Table 10.

Table 10. The broken chain theory.

Stage Division	Condition	Time Proportion	Countermeasure
Prophase	Unfinished destructive power	More than 70%	Chain breaking
Metaphase	Potential destructive power	About 25%	Preventing
Anaphase	Explosive destructive power	Less than 5%	governing

Table 10 divides the occurrence of the disaster chain into three links, including prophase, metaphase, and anaphase. Since the impact of the typhoon on construction sites is unique, we combined its characteristics and disaster chain theory in making warning processes and measures for disaster prevention and mitigation.

The warning flow is shown in Figure 13. After the weather bureau releases the weather information in advance, we judged the level of natural disaster information. If the risk of typhoon is too low, no warning is given. If the natural disaster is between I and IV, the corresponding disaster prevention and mitigation measures are given.

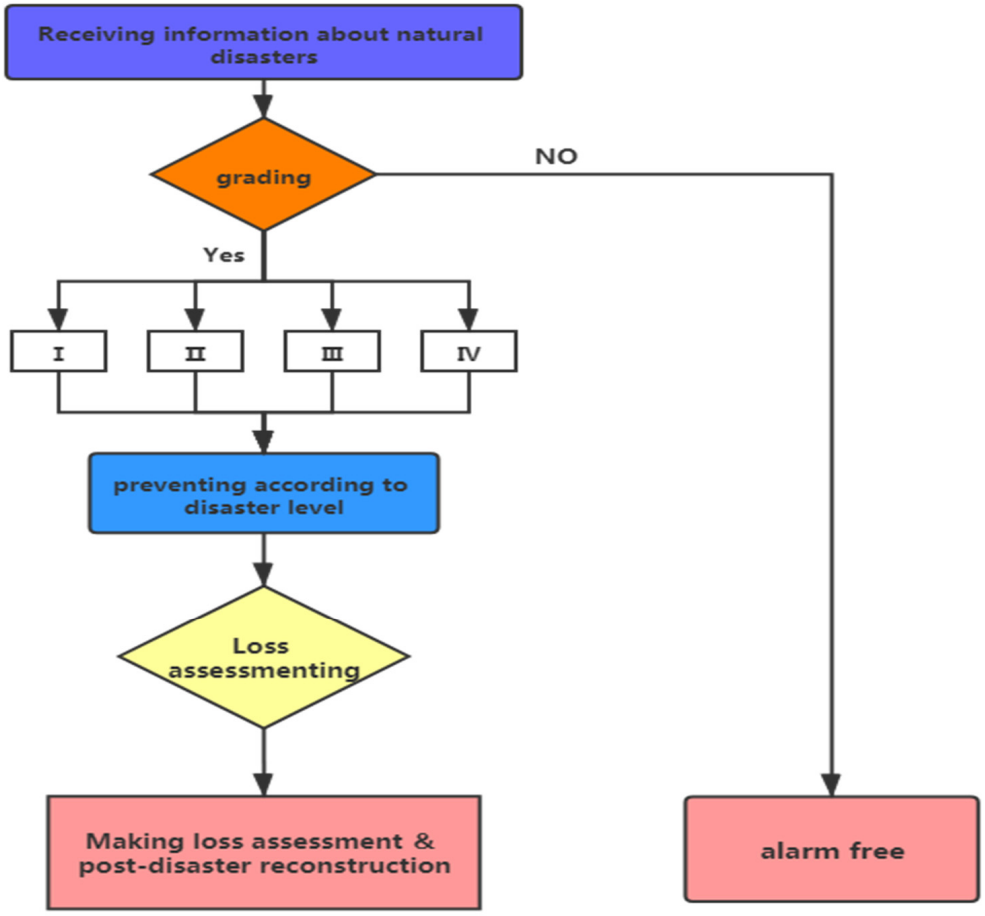


Figure 13. The flow of early warning.

The disaster prevention and mitigation measures are based on the quantitative calculation results of AHP. It can be seen from the calculated data that among the five factors, risk factors account for 39.02%, and disaster prevention index factors account for 25.24%, indicating that we should invest more resources in disaster prevention and mitigation. In this way, disaster prevention resources can be maximized. In the same way, in the sub-indices of these five factors, such as the indicator of disaster prevention capability, we can obtain that the meteorological bureau's prediction accuracy of disasters, the strength of construction safety emergency personnel, and the level of construction safety emergency equipment account for a relatively large proportion. Therefore, we must ensure the accuracy of the disaster level of early warning and carry out targeted prevention during disaster prevention. In addition, we should pay attention to the construction of disaster prevention teams and improve the management level of disaster prevention managers during disaster prevention, use advanced technology to prevent and reduce disasters, and further demonstrate that it is very necessary to use drones to prevent and reduce disasters on construction sites. According to the judgment results of different typhoon levels, we developed detailed measures shown in Table 11.

Table 11. The measures of disaster prevention and mitigation.

Natural Disaster Forecast and Warning Level		
Level	**Standard**	**Solutions**
IV	Low probability happens within 24 h, and low disaster intensity	1. Spot and inspect hidden dangers (no UAV). 2. Stop outdoor operation at the construction site, especially the operation above the tower crane. 3. Transfer essential construction materials and large machinery to protect related structures.
III	Medium probability happens within 24 h, and low disaster intensity	1. Make inspections on hidden dangers with UAVs and collect relevant data. 2. Stop any operation, especially the operation above the tower crane at the site. 3. Transfer important construction materials and large machinery and protect temporary structures.
II	High probability happens in 24 h, and disaster intensity increases rapidly	1. The whole site will be inspected by UAV, and data collection will be conducted. 2. Make use of UAVs to inspect large machinery, especially the connection between tower cranes. 3. According to the results of the UAV inspection, the disaster prevention and reduction working group will be set up immediately to deal with it.
I	Must happen within 24 h, and the largest disaster intensity	1. The whole site will be inspected by UAV, and data collection will be conducted. 2. Make use of UAVs to inspect large machinery, especially the connection between tower cranes and temporary structures. 3. According to the results of the UAV inspection, the disaster prevention and reduction working group will be set up immediately to deal with it.

The application of UAV photography technology in the construction site was verified through the case of Xiamen Electronic City. On the one hand, it used the site photo data obtained by UAV and then used modeling software (smart3D and pix4d mapper) for 3D modeling analysis. On the other hand, 2D image processing and analysis were carried out using the photo data obtained by the UAV. First of all, the single model built by the modeling software (especially the use of smart3D) can reflect every detail of the building with high precision and can provide construction managers with a 360° inspection without dead ends. A short buffer time before a disaster strikes and resources are allocated for defense. For example, if those important construction materials have not been transferred, you can know immediately. In addition, the establishment of the 3D model can be established before and after the disaster, which is conducive to the comparison before and after the disaster, so that the loss can be determined as soon as possible, and a data account can

also be formed. At the same time, it can also analyze which places are most vulnerable to losses, providing valuable experience for the follow-up prevention of similar disasters. Thirdly, through the powerful image processing technology of Matlab software, the high-definition pictures obtained by the drone can be used. For example, the use of drones to inspect large machinery, especially tower cranes, is easy to collapse under typhoon disasters, causing a series of disaster losses. The survey found that most of the tower cranes that collapsed under the typhoon collapsed because of problems in the connection between the tower cranes. Drones can be used to collect photos, and then image processing technology such as denoising, enhancement, transformation measurement, sharpening, and other technologies can be used to effectively identify the location of the tower crane with potential safety hazards and carry out timely protection processing. In a word, UAV photography technology and point cloud processing technology provide strong technical support for the risk control of construction sites under natural disasters, and it is expected to have greater expansion in the automatic detection of construction site risks.

6. Conclusions

The study developed a natural disaster analysis model and a warning flow based on disaster theory and field investigation of the construction site. AHP, as a quantitative analysis method, was applied to calculate the weight ratios of different influence factors in the theoretical model. In the criterion layer of the model, we set five indicators, including risk, exposure, vulnerability, the capability of disaster prevention, and the capability of disaster mitigation. Respectively, at the factor level, we again decomposed 35 influencing indicators. The results show that the intensity of typhoons, the management level of the construction project leader, and the rationality of measures are key factors in the natural disaster model on the construction site. Different factors determine the impact degree of the typhoon. We proposed a more reasonable early warning flow through data analysis and formulated disaster prevention and reduction measures through data analysis.

In the case investigation of the construction site, we used UAV to evaluate cracks in the periphery of some structures and the status of structural joints. We found that using the maneuverability of UAVs can improve the identification speed and significantly save precious time for pre-disaster prevention. As for the information on disaster level warnings, we developed corresponding measures that can improve the management ability of the construction site and lay a theoretical foundation for the prevention and reduction of typhoons.

Given the wide range and complex terrain of construction sites, it is impossible to conduct all-around detection when using UAVs for pre-disaster inspection. Therefore, further studies are recommended to seek potential in improving UAV detection comprehensiveness by optimizing path planning and collecting parameters. The paper systematically introduces and analyzes establishing an early warning process and making disaster prevention and reduction measures. Although the study does not cover all types of typhoons and all periods of construction sites, it provides feasible ideas for similar studies. It also helps to extend the application of UAVs in the early warning detection of the construction industry during a natural disaster to realize the development of industrial automation technology. Therefore, the future development direction of this research is to achieve intelligent detection and automated collection and analysis of construction site safety information.

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