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Research on Ethical Risks of Digital Technology and Mitigation Strategies on Smart Construction Sites

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Abstract

With the widespread application of digital technologies on smart construction sites, ethical risks have become increasingly prominent, potentially provoking strong negative public sentiment and impeding the project process. This study investigates the ethical risks associated with digital technologies on smart construction sites and examines the mechanisms shaping public perceptions of these risks. Employing clear set qualitative comparative analysis (csQCA) and analyzing 30 actual cases, the study identifies key combinations of conditions that trigger public perceptions of ethical risk. The results show that high ethical risks on smart construction sites are not attributed to any single condition in a linear fashion, but rather emerge through three distinct pathways. Based on these findings, we recommend that, in promoting the development of smart construction site technologies, stakeholders should enhance technological supervision, strengthen data protection, and improve communication and coordination among all parties in the construction industry. Additionally, it is necessary to establish an ethical governance framework that incorporates the principles of the United Nations Sustainable Development Goals, emphasizing dynamic governance and worker participation. This study provides both a theoretical foundation and practical guidance for balancing technological innovation with ethical risk prevention on smart construction site practices.

Keywords: smart construction sites, ethical risks, resolution paths, qualitative comparative analysis, Clear Set Qualitative Comparative Analysis (csQCA)

0. Introduction

At the 23rd meeting of the Central Committee for Comprehensively Deepening Reforms, General Secretary Xi Jinping (2022) emphasized that scientific and technological ethics represent indispensable value criteria in scientific and technological activities. As competition in science and technology intensifies, related ethical issues and challenges are also becoming more prominent. The development of emerging technologies introduces new ethical dilemmas, while the convergence of diverse technological fields gives rise to increasingly complex ethical concerns. Against this backdrop, the Chinese government has introduced a series of policies to enhance the development of science and technology ethics.For example, between 2019 and 2024, the Central Committee for Comprehensively Deepening Reforms, the offices of the Communist Party of China Central Committee and the State Council, as well as ten other departments, successively issued plans, opinions, and measures to promote the construction of a scientific and technological ethics governance system and to strengthen risk prevention and control.

The ethical governance of smart construction sites is not only essential for technological advancement and standardized industry development, but is also closely linked to the United Nations Sustainable Development Goals (SDGs)—particularly SDG 9 (Industry, Innovation and Infrastructure) and SDG 11 (Sustainable Cities and Communities). As a key vehicle for the digital transformation of the construction sector, smart construction sites drive infrastructure innovation and contribute to the sustainable development of urban communities. Effective ethical governance in this context supports both progress toward these SDGs and the harmonious, sustainable development of the industry and society as a whole.

The academic community has explored ethical risks arising from digital technologies through a range of studies. For example, Liu Tianyu (2021) argued that algorithmic development can alienate organizational members and trigger ethical crises within organizations. Wang Jingyi (2023) found that modern technologies are susceptible to abuse, leading to problems such as "panoptic surveillance." Zhang Ting (2022) examined the governance of ethical risks in artificial intelligence using collaborative governance approaches, and Tian Xuming (2022) systematically analyzed key ethical risks in digital society, including data and information security. Additionally, Li Lun and colleagues considered essential principles for scientific and technological ethics governance, particularly proportionality (Li & Ling, 2020). The 2024 report "Leveraging the 'Smart Brain' to Enhance Supervision Efficiency—Fengcheng City Housing and Urban-Rural Development Bureau Builds a Smart Construction Sites Supervision Platform" highlighted the urgent need to address ethical issues specific on smart construction sites (Fengcheng City Housing and Urban-Rural Development Bureau, 2024).

While considerable research has addressed the ethical risks of digital technologies in contexts such as educational reform, relatively few studies focus specifically on smart construction sites. Existing research in this area mainly centers on risk identification and countermeasures, seldom addressing the interactive and interdependent relationships among risk factors. To address this gap, the present study utilizes csQCA to analyze 30 cases—26 of which come from 16 urban housing and urban-rural development bureaus across China, and 4 from two project interviews in Chengdu—employing fsQCA3.0 software to identify solutions and offer targeted recommendations for mitigating ethical risks associated with digital technologies in smart construction sites.

1. Conceptual Framework and Research Subject

1.1 Smart Construction Sites and Digital Technologies

Smart construction site systems employ information-based technologies to achieve intelligent construction processes, real-time resource sharing, and data-driven decision-making, effectively addressing challenges that traditional management models face in large-scale and complex projects. The system architecture typically consists of three layers:

(1) Perception Layer: This layer gathers information about materials, personnel, equipment, and other assets on the construction site via sensors, RFID tags, GPS, and similar devices.

(2) Network Layer: This layer facilitates information transmission through wired and wireless networks, such as WLAN and optical fiber.

(3) Application Layer: Here, collected data undergoes intelligent analysis and processing, supporting the formulation of operational solutions.

These systems are widely deployed for construction safety management, supporting hazard identification and mitigation. They foster a management model characterized by interconnection, coordination, information sharing, online monitoring, and intelligent early-warning.

Building Information Modeling (BIM) technology plays a central role by establishing three-dimensional models of construction projects, creating a comprehensive engineering information database comprising geometric data, professional attributes, and status information. Key features of BIM include visualization, coordination, simulation, optimization, and drawability. Its application throughout the project lifecycle promotes data sharing, collaborative work, higher efficiency, and cost reduction.

The Internet of Things (IoT) further enhances operational transparency by connecting objects on-site via sensors, RFID, and GPS. IoT enables intelligent identification, monitoring, and management of people, machines, materials, construction methods, and environmental conditions. For example, IoT devices manage personnel safety through smart chips and track large components with QR codes.

Intelligent technologies—integrating computer science, advanced sensor technology, and GPS positioning—improve working environments, boost efficiency, reduce risks and maintenance costs, and support environmental protection and energy savings.

Mobile internet technology, known for its interactivity, convenience, and location tracking, rapidly transmits information such as images and video via mobile devices, enabling timely feedback and issue tracking. This is particularly valuable for remote construction sites, preventing losses due to information transmission delays.

1.2 Ethical Risks of Digital Technologies on Smart Construction Sites

Ethical risks posed by digital technologies are primarily multi-dimensional, arising from the intrinsic complexity and uncertainty of emerging technologies as well as their interactions with external environmental and organizational factors. Scholars generally categorize these risks into two main types. The first type encompasses the negative ethical impacts on relationships among humans, between humans and nature, and within broader social relations resulting from technological advancement (Wu et al., 2020). The second type relates to systemic risks induced by technological applications, including imbalances in ethical relationships, social disorder, and ecological harm. Such risks are particularly apparent when technology is repurposed as a tool for capital control.

In the context of construction engineering, ethical risks associated with digital technologies on smart construction sites are closely linked to issues of physical safety and the potential for mass casualty events (such as structural collapses caused by mechanical failures). These risks involve complex chains of responsibility and are especially susceptible to data manipulation. In contrast to other sectors—such as healthcare or finance—where digital technology ethics often focus on individual rights or financial damages with relatively well-defined responsible parties, ethical risks in smart construction sites tend to be project-specific, complex, and uncertain. Their influence extends throughout the project lifecycle, generating negative ethical consequences for multiple stakeholder groups. These effects are often manifested as ethical conflicts within interpersonal, ecological, and social domains.

Drawing on prior research, this paper summarizes the principal categories of ethical risks posed by digital technology on smart construction sites, including (Wang, 2023; Tian, 2022; Mao & Dong, 2023; Liu & Liu, 2021): risks related to data and information privacy leakage; risks due to unclear technological accountability mechanisms; ethical risks in human–machine interactions; erosion of labor ethics; managerial dysfunction resulting from excessive reliance on technology; ethical risks stemming from conflicts of interest among technology developers, providers, and users; and potential risks associated with insufficient legal frameworks governing technology. This paper will focus on defining five core categories of technological ethical risk and identifying potential issues within each category (see Table 1).

Table 1. Key Categories of Technological Ethical Risks

Risk Category	Risk Definition	Potential Ethical Risk Issues
Information Privacy Ethical Risk	Algorithmic power extends infinitely into cyberspace, enabling real-time surveillance of users and behavioral disciplining through technical directives.	Privacy data leakage、Misuse of private data、Abuse of private data leading to detriment to individual or corporate interests.
Labor Ethics Erosion Risk	Machines become a form of capital and a power to dominate labor (*An, Huang, & Li, 2024*).	Workers are compelled to become high-intensity 'precision machines' to relatively extend the surplus labor time that can be appropriated without compensation (*Guo, Jiang, Jiang, Liu, & Deng, 2024*).
Accountability Mechanisms Ambiguity Risk	Risks arising from the inability to obtain compensation based on existing laws and regulations, or falling into legislative gaps regarding accountability.	Enterprises often cite neutrality of use as an excuse for avoiding responsibilities that should be shared by researchers and developers, designers and manufacturers, and those who deploy and apply them.
Technological Over-Reliance Risk	Risks associated with excessive dependence on technology, leading to weakened management skills, employee unemployment, and technological vulnerability.	Regarding technological vulnerability risks: Over-reliance on digital technologies by application parties may lead to the neglect of issues related to technological vulnerabilities.
Fairness and Justice Ethical Risk	Risks concerning fairness and justice in market competition and for vulnerable groups.	I. Market Competition Fairness and Justice Risk: Technological upgrades in smart construction sites may intensify market competition unfairness (*Liu & Liu, 2021*), subsequently altering traditional project bidding standards and widening profit disparities. Long-term effects could potentially trigger market monopoly risks. II. Vulnerable Groups Fairness and Justice Risk: The introduction of digital technologies may undermine social fairness and justice (*Tan & Yang, 2019*).

2. Theoretical Framework and Research Methods

In social science research, traditional statistical methods often fall short when addressing complex problems that involve small sample sizes and numerous intertwined factors. Such methods may struggle to capture and analyze the intricate causal pathways between variables. By contrast, qualitative comparative analysis (QCA) provides a systematic framework for inferring complex causal relationships, especially in small-sample studies, using configurational comparison logic. The QCA approach was first introduced in 1987 by American sociologist Charles C. Ragin, initially in political science and historical sociology, as a means to "integrate case-oriented and variable-oriented approaches" (Ragin, 1987). This method leverages a configurational approach to analyze cases and uncover complex, concurrent causal relationships. Today, QCA is widely used in sociology, management, economics, and increasingly in construction engineering.

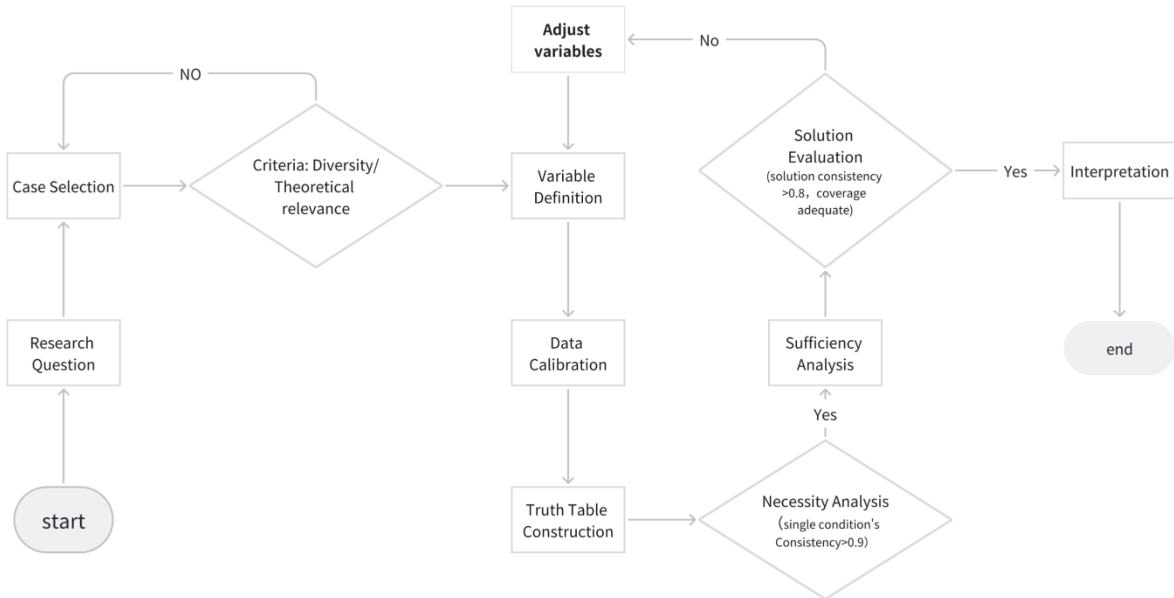

Figure 1. csQCA Method Flowchart

Given the small sample size in this study and the clearly dichotomous nature of the condition and outcome variables, we employ clear set qualitative comparative analysis (csQCA) to examine the ethical risks associated with digital technologies in smart construction sites, focusing on public perception and mitigation pathways. Compared to other QCA variants, csQCA emphasizes representativeness and is well-suited for studies with limited case numbers (see methodological process in Figure 1). Its lower dependence on large sample sizes further enhances csQCA's suitability for this research. Accordingly, this study selects 30 cases of ethical risks in smart construction sites (see Table 2) as the empirical basis for analyzing risk mitigation mechanisms.

Table 2. Selected Case Information

Case of Digital Ethical Risks in Smart Construction Sites			
No.	**Case Date**	**Case Name**	**Ethical Risk Type**
1	2019.08	Chengdu Construction Site Dust Monitoring Data Fraud Incident	Unclear Technical Accountability Mechanism
2	2022.11	Foshan Construction Site Attendance Fraud Incident	Fairness and Justice
3	2023.04	Dongguan Linyue Garden Project Attendance Data Fraud Incident	Labor Ethics Erosion
4	2022.08	Zhejiang New Love Network Technology Data Leak Incident	Information Privacy
5	2016	Issues in the Supervision of 'Smart Construction Sites' in City C	Labor Ethics Erosion
6	2021.04	Inspection Report on Smart Construction Sites Applications and Data Integration by Nantong Fanhua Construction Co., Ltd.	Over-Reliance on Technology
7	2020.12	Inspection Report on Smart Construction Sites Development in Suqian by the Housing and Urban-Rural Development Bureau	Over-Reliance on Technology
8	2020.12	Challenges in Informatization Supervision of Wenzhou Smart	Over-Reliance on

		Construction Sites	Technology
9	2022.12	Practices in Jiangyin Smart Construction Sites Development	Over-Reliance on Technology
10	2022.05	Service Quality Evaluation Case of Attendance Equipment Suppliers in Nanhai District, Foshan	Fairness and Justice
11	2024.01	Report on the Assessment of Intelligent Construction Pilot Projects in Suzhou for Q4 2023	Over-Reliance on Technology
12	2020.10	Shaoxing Official Report on Fraudulent Test Results of Rail Transit Engineering: 4 Companies Penalized	Fairness and Justice
13	2019.07	Report on the Progress of Smart Construction Sites Development in Chengdu	Over-Reliance on Technology
14	2023	AI Monitoring Failure at a Chengdu Smart Construction Sites: Unrecognized High-Altitude Worker Without Safety Harness Resulting in Fatality	Over-Reliance on Technology
15	2021.10	Regulatory Violation Incident by Wuzhong Shuntong Construction Engineering Co., Ltd.	Fairness and Justice
16	2023	Data Fraud Incident at a Shenzhen Smart Construction Sites Project	Over-Reliance on Technology
17	2023	Data Leak Incident at a Shanghai Construction Group	Over-Reliance on Technology
18	2024	Yantai Construction Site Dust Monitoring Data Fraud Incident	Unclear Technical Accountability Mechanism
19	2019	Attendance Fraud Incident at Xiuzhou Construction Site	Fairness and Justice

2.1 Variable Selection

The cases referenced above were selected by searching for the keywords "smart construction sites" and "ethical risk" in core journals within the China National Knowledge Infrastructure (CNKI) database. Comprehensive literature analysis yielded four secondary indicators—stakeholder harm, accountability evasion, communication and coordination, and technology integration—alongside eight tertiary indicators: harm target, vulnerability impact, violation cost, technology dependence, clear attribution, institutional safeguard, field engagement, and IoT technology linkage (see Table 3).

Table 3. Assignment of Outcome Variables and Condition Variables

Variable Type		Variable Name	Description of assignment criteria	Value
Outcome Variable	Public Perception Outcome	Public Perception	Aware of Risks	1
			Unaware of Risks	0
Condition Variable	Stakeholder Harm	Harm Target	Owner Harm	1
			Other Stakeholder Harm	0
		Vulnerable Impact	Vulnerable Groups Harmed	1
			Vulnerable Groups Unharmed	0
		Violation Cost	High Violation Cost	1
			Low Violation Cost	0
	Account-ability Evasion	Technology Dependency	Technology Dependent	1
			Technology Independent	0
		Clear Attribution	Clear Responsibility Attribution	1
			Unclear Responsibility Attribution	0
		Institutional Safeguard	Institutional Safeguard Present	1
			Institutional Safeguard	0

		Absent	
Communica-ion Coordination	Field Engagement	Real-Time Communication	1
		No Real-Time Communication	0
Technology Integration	IoT Technology Linkage	IoT Technology Utilized	1
		IoT Technology Not Utilized	0

2.2 Univariate Necessity Analysis

In employing the QCA approach, it is common to first profile individual explanatory variables to assess whether any serve as sufficient or necessary conditions for the emergence of ethical risks in digital technologies at smart worksites. Prevailing academic standards dictate that a consistency score above 0.8 indicates sufficiency, while a score above 0.9 denotes necessity. As shown in Table 4, "technology dependence" and "IoT technology linkage" both achieved consistency scores of 1, demonstrating that they are necessary conditions for public perception of ethical risk. Other variables, which scored at or below 0.8 in consistency, did not independently trigger ethical risks, highlighting the need for additional analysis of conditional combinations.

Table 4. Univariate Necessity Analysis

Explanatory Variable	Consistency	Coverage
Harm Target	0.000000	0.000000
Violation Cost	0.500000	0.500000
Technology Dependency	1.000000	0.275862
Clear Attribution	0.250000	0.200000
Institutional Safeguard	0.250000	0.181818
Communication Coordination	0.000000	0.000000
IoT Technology Linkage	1.000000	0.296296
Vulnerable Impact	0.375000	0.200000

2.1.2 Variable Calibration

Given the dichotomous nature of the variables in this study, the csQCA method was chosen. Each variable was binary-coded (0/1) according to the definitions in Table 3, generating the dichotomous dataset presented in Table 5.

Table 5. Dichotomous Coding of Ethical Risk Variables

Code	Criterion	Value	Cases	Proportion
PP	Aware of Risks	1	8	26.67%
	Unaware of Risks	0	22	73.33%
HT	Owner Harm	1	7	23.33%
	Other Stakeholder Harm	0	23	76.67%
VC	High Violation Cost	1	7	23.33%
	Low Violation Cost	0	23	76.67%
TD	Technology Dependent	1	29	96.67%
	Technology Independent	0	1	3.33%
CA	Clear Responsibility Attribution	1	10	33.33%
	Unclear Responsibility Attribution	0	20	66.67%
IS	Institutional Safeguard Present	1	10	33.33%
	Institutional Safeguard Absent	0	20	66.67%
C&C	Real-Time Communication	1	3	10.00%
	No Real-Time Communication	0	27	90.00%
IoT-L	IoT Technology Utilized	1	27	90.00%
	IoT Technology Not Utilized	0	3	10.00%
VI	Vulnerable Groups Harmed	1	15	50.00%
	Vulnerable Groups Unharmed	0	15	50.00%

2.3 Truth Table and Combinatorial Analysis

The truth table (Table 6) enumerates all possible combinations of conditions (with eight binary variables, there are theoretically 28=256 combinations). The analysis was conducted using fsQCA3.0 software, which generates three types of solutions: complex, intermediate, and parsimonious. The intermediate solution was adopted for analysis in this study, with the coverage metric used to represent explanatory power and the consistency metric used as a measure of sufficiency.

Table 6. Truth table

No.	PP	HT	VC	TD	CA	IS	C&C	IoT-L	VI
1	1	0	1	1	0	1	0	1	0
2	0	1	1	1	1	1	0	1	1
3	0	1	0	1	1	0	0	1	1
4	0	0	0	1	0	0	0	1	0
5	1	0	0	1	0	0	0	1	1
6	0	0	0	1	1	0	0	1	0
7	0	0	0	1	0	0	0	1	1
8	0	0	0	1	0	0	0	1	1
9	0	0	0	1	0	0	0	1	1
10	0	0	0	1	0	0	0	1	1
11	0	0	0	1	0	0	0	1	1
12	0	0	0	1	0	0	0	1	1
13	0	0	0	1	0	0	0	1	1
14	1	0	0	1	0	0	0	1	1
15	0	0	0	1	0	0	0	1	0
16	0	1	1	1	1	1	0	1	1
17	0	1	0	1	0	0	0	1	0
18	0	1	0	0	1	1	0	0	0
19	0	1	1	1	0	1	0	1	1
20	0	0	0	1	0	0	0	1	0
21	0	0	0	1	0	0	0	0	0
22	0	0	0	1	0	1	1	1	0
23	0	1	0	1	1	1	1	1	0
24	0	0	0	1	1	1	1	1	0
25	1	0	1	1	1	0	0	1	0
26	0	0	0	1	1	1	0	0	1
27	1	0	1	1	1	0	0	1	0
28	1	0	0	1	0	0	0	1	0
29	1	0	1	1	0	0	0	1	0
30	1	0	0	1	0	1	0	1	1

This study strictly adhered to the principle of robust variable selection, comparing and coding eight conditional variables against a single outcome variable. The fsQCA3.0 software, in conjunction with Boolean minimization algorithms, was utilized to compute and simplify complex configurations of condition and outcome variables, resulting in one valid configuration (among the 256 theoretical possibilities). Coverage and consistency tests were conducted to verify the validity of the identified relationships.

The coverage test and consistency test were used to confirm whether relationships among variables satisfied the necessary theoretical conditions. Coverage measures the extent to which all configurations of the conditional variables account for the observed outcomes—the higher the coverage value, the greater the explanatory power of the conditional configurations. Consistency, on the other hand, tests whether the conditional variables serve as sufficient conditions for the outcome variable.

After running the QCA software, three solutions of varying complexity were generated: the intermediate solution, the complex solution, and the parsimonious solution. These represent the analysis results for sufficiency and necessity of conditions in the truth table. Drawing on established QCA research, the intermediate solution is typically selected for further analysis, as it best balances explanatory depth and parsimony. Therefore, this study also adopts the intermediate solution as the basis for the configuration analysis. Net coverage refers to the explanatory power uniquely attributable to a specific conditional configuration, independent of overlap with other configurations explaining the same outcome. Detailed results are presented in Table 7.

Table 7. Analysis Structure of Configuration

Solution Type	Configuration	Raw Coverage	Net Coverage	Consistency
Complex	～HT*VC*TD*～IS*～C&C*IoT-L*～VI	0.375	0.25	1
Intermediate	～HT*VC*TD*～IS*～C&C*IoT-L*～VI	0.375	0.25	1
Parsimonious	～HT*VC	0.5	0.375	1

Note: '*' indicates logical AND ,'~' indicates logical NOT

According to theoretical guidelines, when consistency exceeds the threshold value of 0.8, the configuration is considered sufficiently consistent. In this study, the intermediate solution yielded a coverage rate of 0.375 and a consistency of 1.0, demonstrating the strong persuasiveness, coverage, and validity of the identified configuration, with significant explanatory power for ethical risks on smart construction sites.

2.4 Case Configuration Analysis

Counterfactual analysis was conducted to identify both the intermediate and parsimonious solutions within the configuration space. These solutions were compared to distinguish between core and peripheral conditions, following the csQCA result expression recommended by Fiss. In this convention, core conditions—either present or absent—appear as '●' or '⊗', while edge (peripheral) conditions are indicated by '•' or '⊙'; a blank indicates that the presence or absence of the condition does not affect the configuration derived for a particular solution. Based on this logic, Table 8 presents the antecedent condition constructs for ethical risks on smart construction sites.

Table 8. Antecedent Conditional Constructs of Ethical Risks in smart construction sites

	parameterisation1a	parameterisation1b	parameterisation2
HT	⊗	⊗	⊗
VC	●	●	⊙
TD	•	•	•
CA		⊙	⊙
IS	⊙		●
C&C	⊙	⊙	⊗
IoT-L	•	•	●
VI	⊙	⊙	•
Consistency	1	1	1
Original Coverage	0.375	0.25	0.125
Net Coverage	0.25	0.125	0.125
Overall Consistency	1		
Overall Coverage	0.65		

Through analysis of the groupings formed by different condition combinations, three main configurations emerged, each with strong explanatory strength. These are summarized and described as follows:

(1) High Violation Cost –Harm Target to Other Stakeholder Types

a) High Violation Cost – Harm Target to Other Stakeholder (Institutional Safeguard Absent) Type

This configuration describes conditions under which public perception of ethical risk arises: specifically, when harm is inflicted on other stakeholder than direct owners, when the violation incurs a high cost, and when there are no effective institutional safeguards. Case 1, "Falsification of Dust Monitoring Data at Construction Sites in Chengdu," fits this construct well.

In this case, the companies Zhijiantong (Chengdu) Technology Co., Ltd. and Chengdu Xinhaoyue Technology Co., Ltd., both providers of dust-monitoring equipment, were blacklisted by the Chengdu Municipal Housing and Urban-Rural Development Bureau after being found to have engaged in data falsification. These companies received a one-year ban on market entry (from August 12, 2019, to August 11, 2020). Notably, the dust-monitoring equipment provided for major projects—including the “Chengdu First Wastewater Treatment Plant” and the “Hengda Xinhong Plaza Building Project”—contained technical vulnerabilities that permitted transmission of falsified data during power outages.

Furthermore, both the equipment operators and project contractors failed in their management responsibilities and attempted to shift blame to one another, which drew significant public attention. Fabrication of dust monitoring data during power interruptions has deprived local residents of accurate environmental information, significantly jeopardizing public health and violating third-party interests.

In response, regulatory authorities enforced strict measures, including: banning the implicated companies from future equipment installations in Chengdu, mandating technical rectification and recall of defective products, and requiring the companies to guarantee maintenance quality for deployed systems. These actions resulted in substantial financial penalties. The case also exposed major gaps in current institutional frameworks for exceptional circumstances such as power outages, notably the absence of regulations requiring immediate reporting and compensatory measures to maintain real-time data accuracy in such situations (Zhengzhou Municipal Urban-Rural Development Bureau, 2019).

b) High Violation Cost – Harm Target to Other Stakeholder (Unclear Responsibility Attribution) Type

This configuration occurs when high-cost violations adversely affect other stakeholder, and when responsibility attribution is unclear. Case 29 provides a typical example.

In this case, several construction sites in Yantai were found to have deliberately shut down monitoring equipment, tampered with range limits, or physically interfered with monitoring data. Responsibility for these actions was unclear, with both construction contractors and equipment providers evading liability. Eventually, the Yantai Ecological Environment Bureau imposed fines on the responsible parties. For example, Yantai Suokun Glass Container Co. Ltd. was fined $108,000 for manipulating automated monitoring data, referred to the public security authorities, and ordered to rectify the situation within a specified period. The resulting interest losses were substantial.

This case demonstrates that data manipulation or interference can lead to anomalous readings that mask excessive emissions, potentially polluting downstream commercial and residential areas and infringing on third-party interests. Furthermore, the ambiguity in responsibility attribution led to blame-shifting between involved parties. Ultimately, regulatory intervention imposed heavy financial losses and mandatory rectification upon the offending companies (Hou & Wang, 2020).

(2) Institutional Safeguards –Vulnerable Groups Harmed Type

This configuration demonstrates the public perception of ethical risk when there is a lack of institutional safeguard and the harm to vulnerable groups. The case that best fits this conformation is Case 30.

In 2019, as part of the “Smart Construction Sites” initiative in Xiuzhou District, inspections of 152 construction sites uncovered violations such as proxy card swiping, incomplete attendance records, and falsified logs. These irregularities not only disrupted site operations, but also risked labor disputes, safety hazards, and regulatory non-compliance.

In response, authorities ordered the involved enterprises to implement corrective measures within a stipulated timeframe. Administrative penalties, as outlined in the Hangzhou Smart Construction Sites Real-Name Attendance Management Measures, included: deductions of credit scores, incorporation of violations into corporate credit records, revocation of eligibility for project awards, and public disclosure of the offending projects and companies. This case highlights the dual need for advanced technology and rigorous management in developing smart construction sites. It underscores the importance of: strengthening accountability mechanisms across all stakeholders; integrating reliable attendance technologies; and enhancing enforcement and oversight in order to minimize management loopholes and safeguard ethical standards (Yu & Huang, 2019).

3. Recommendations for Countermeasures

3.1 Establish Robust Ethical Oversight and Accountability Mechanisms

Attribution of responsibility is a critical issue contributing to ethical risks on smart construction sites. Interviews conducted in this study reveal that many construction companies purchase IoT equipment and related services as a result of mandatory government requirements. In some regions, procurement is further restricted by government-designated suppliers, leading to reduced market competition, technological monopolies, and poor product quality.

The Heze Urban and Rural Administration Bureau addressed this by introducing open, transparent, and competitive procurement processes for IoT projects. By issuing competitive consultation announcements and preventing supplier monopolies or service quality issues, the Bureau sought to promote best practices and accumulate valuable experience for the industry (Heze City Housing and Urban-Rural Development Bureau, 2022). In addition to improving procurement transparency, unclear responsibility attribution can be mitigated by involving the public in oversight and supervision. For example, a bulletin board at smart construction sites displaying company contacts or a QR code for complaints would allow the public to report violations, thereby enhancing accountability.

3.2 Strengthening Technical Regulation and Data Protection

It is common for smart construction sites to place excessive trust in machine- or system-generated data. However, such data can be vulnerable to authenticity issues, including tampering. To address these risks, enhanced technical supervision and data protection are needed.

A notable example is found in the Chengdu Hi-Tech Zone, where digital Yuan was used to pay migrant workers' wages in two construction projects. Through real-name authentication, smart contract payment, and blockchain technology, wages were earmarked and monitored in real time, establishing a robust closed-loop evidentiary chain and resolving longstanding problems of "unclear accounts" in the construction industry. This example demonstrates that strengthening technical oversight and data protection can improve data authenticity, safeguard workers' rights, promote innovation in social governance, bolster public trust in smart construction sites, and pave the way for wider adoption.

3.3 Develop an Ethical Governance Framework for Smart Construction Sites

This study recommends constructing an ethical governance framework for smart construction sites that aligns with the United Nations Sustainable Development Goals (SDGs). Policy measures should include strengthening data management and embedding data ethics into international standards, specifically by integrating data ethics provisions into the ISO 19650 framework and mandating full lifecycle data traceability within Building Information Modeling (BIM) systems to ensure transparency and auditability.

These actions will accelerate digital transformation in the construction industry, prevent resource waste and environmental harm resulting from poor data management, and provide a solid foundation for sustainable infrastructure development. At the same time, the protection of worker rights and the promotion of fair working environments require the establishment of on-site ethics committees, ensuring workers participate in technological decision-making processes. As the direct participants and most affected group, empowering workers enables comprehensive assessment of technology's impact on workplace conditions, safety, and health; mitigates risks associated with indiscriminate technological deployment; and advances social equity and industrial harmony.

4. Limitations and Prospects

Despite using the csQCA method and analyzing 30 cases of ethical risks in smart construction sites, this study has certain limitations. Chief among these is the relatively limited sample size, which should be supplemented and extended in subsequent research. Future studies are encouraged to incorporate international cases to broaden the application scope.

Smart construction sites is an inevitable trend for the future development of the construction industry, and its successful implementation will affect the entire industrial chain, from design, construction to operation and maintenance will usher in a huge change. With the wave of digitization sweeping the world, digital technology continues to develop, and social values are also changing. Under the background of this dynamic change of 'science and technology-society', the governance of digital science and technology ethics in the smart construction sites should also be dynamic, and it is necessary to explore the ethical hazards and potential risks, and put forward the corresponding solutions to solve the problem. We need to constantly explore the ethical pitfalls and potential risks, and propose corresponding solutions to improve the governance system and realize the efficient application and governance of technology.

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