RESEARCH ARTICLE

Understanding the Determinants of Blockchain Adoption in the Engineering-Construction Industry: Multi-Stakeholders' Analyses

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ABSTRACT Blockchain technology is promising toward transforming conventional construction practices to improve collaboration and integration management in engineering-construction projects. The factors affecting the adoption of blockchain technology from the different stakeholder perspectives, however, have not been thoroughly investigated. Following the theory of planned behavior (TPB) and regulatory focus theory (RFT), this study explores the formation mechanisms underlying blockchain adoption from a multi-stakeholder perspective. The model was tested through partial least squares-structural equation modeling (PLS-SEM) and the fuzzy-set qualitative comparative analysis (fsQCA) method using data collected from Chinese construction practitioners. PLS-SEM results indicate that institutional pressures, perceived functional benefits, and behavioral control can directly drive blockchain adoption. Although perceived symbolic benefits do not directly affect blockchain adoption, their indirect effects on adoption are fully mediated by adoption intention. The PLS multi-group analysis found multiple path differences among stakeholders. The fsQCA results show that no single factor or its negation is the necessary condition to trigger blockchain adoption. The configuration analysis results show four new configurations that trigger the adoption of blockchain technology by owners, contractors, and consultants. This first multi-stakeholders research in the field of technology adoption contributes to the explanatory context of TPB and provides new insights into the effective blockchain technology adoption via the identified configurations that suit the project stakeholders.

INDEX TERMS Blockchain adoption, multi-stakeholders, PLS-SEM, fsQCA, engineering-construction industry.

I. INTRODUCTION

In the context of Industry 4.0, and Intelligent Construction, various digital information technologies are emerging in the construction industry to improve project performance regarding project design, construction, and operation stages [1]. In particular, blockchain and blockchain-enabled smart contract technology, as a trusted third party, can automatically verify and permanently record transactions [2] and has recently garnered interest among researchers and

practitioners [3]. Blockchain technology has the potential advantages of automated recording of construction activities in an immutable and transparent way [4], [5] which improves collaboration environments required by engineering-construction projects, and it promotes efficient supply chain management in the construction supply chain and procurement process [6]. For example, the integration of blockchain and Building Information Modeling (BIM) can solve the ambiguity of rights and responsibilities, unclear property rights, and security issues in the BIM collaboration environment. Blockchain technology also enables automatic execution of construction contracts by deploying smart

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contracts, thereby minimizing contract disputes, payment delays, and opportunism.

However, the adoption of blockchain technology in the engineering-construction industry remains limited [7]. The low innovation, discontinuity, and complex construction processes of the engineering-construction industry may lead to differences in technical, organizational, and environmental factors [8] that determine whether organizations will adopt blockchain technology. Furthermore, studies on blockchain adoption are still in the fledging stage [6], [9], and prior studies have primarily focused on conceptual research [10] or employed the traditional symmetric approach [11]. Blockchain adoption is a complex process with complex contextual conditions [12], resulting in managerial decisions based on symbiotic interactions. Because the causal interactions are complex, merely assessing linear relationships may obscure the complexities behind the decision to adopt blockchain technology. Moreover, blockchain technology is a collaborative platform [13] that requires joint cross-functional and inter-organizational stakeholder involvement to maximize its potential and provide effective supply chain governance [14], especially in the multi-organizational engineering-construction context. Understanding the differences in views among the stakeholders could be used to target specific stakeholders to achieve a more focused and efficient blockchain technology rollout [15], [16].

To address these research gaps, this study develops an adoption model for blockchain technology grounded in the theory of planned behavior (TPB) and regulatory focus theory (RFT) from the perspective of multiple stakeholders. In particular, the underpinning objectives of this study are *(1) to determine the direct effects of determinants toward promoting blockchain adoption from a multi-stakeholder perspective and (2) evaluate the complexity of attribute configuration that leads to high blockchain adoption by the key project stakeholders in the industry.*

Our approach begins by combining a literature review and expert opinions to identify potential determinants and existing adoption models. Subsequently, the data collected through questionnaire surveys were analyzed using partial least squares-structural equation modeling (PLS-SEM) and fuzzy-set qualitative comparative analysis (fsQCA), followed by a discussion of the results and final conclusions. The scope of stakeholders in this study focuses on owners, contractors, and consultants in the Chinese engineering-construction industry. As the key project stakeholders, they are the most likely candidates to adopt blockchain technology.

II. CONCEPTUAL BACKGROUND
A. POTENTIAL FACTORS AFFECTING BLOCKCHAIN ADOPTION IN THE ENGINEERING-CONSTRUCTION INDUSTRY

Blockchain technology has been applied in various industries [17], such as agriculture, automobile, finance. Most previous studies have used the technology-organization-environment (TOE) framework or its model combined with other theories to analyze the direct factors affecting blockchain adoption [18], [19]. Some researchers have examined adoption factors from a single perspective [5], [6], [20]. Other researchers only mention adoption factors without empirical validation [20], [21]. Most studies focus only on linear effects and overlook any joint effects among variables [5], [6], [20]. Few studies have comprehensively validated the configurational effects of TPB-based antecedents.

The literature relevant to the determinants of blockchain adoption in the engineering-construction industry is summarized in Table 1, revealing four important categories of factors that influence blockchain adoption: technological benefits and traits, organizational conditions, external environment, and decision features. For example, Wu et al. [5] systematically summarized ten technological, organizational, and environmental challenges related to blockchain adoption in construction practices. Xu et al. [6] found that a lack of information technology infrastructure and legal and regulatory uncertainty are the most prominent barriers toward blockchain adoption in the architectural engineering and construction (AEC) industry. Similarly, Sadeghi et al. [9] showed that organizational communication and information are exposed to higher risk using blockchain technology through case studies, and developed a conceptual blockchain technology risk management framework. Furthermore, Badi et al. [22] assessed the TOE framework using a deductive questionnaire-based approach. The results revealed that supply chain pressure, competitive pressure, top management support, and observability significantly influence the adoption of smart contracts in the UK construction industry.

B. EXTENSION OF THEORY OF PLANNED BEHAVIOR

Various theories have been developed to predict the contextual antecedents of innovation adoption in the engineering-construction field at the organizational level [26]. In the context of the engineering-construction industry, each construction stakeholder represents an independent entity in which top managers individually or collectively govern the organization's behavior [27], including decision-making as to whether to adopt blockchain technology. Moreover, these top managers are not isolated and make decisions based on the organization's external environment and internal conditions. As a result, this research is built on TPB, a widely used theoretical lens used to study user acceptance of various technologies in different contexts, including the engineering-construction industry. Although TPB was initially developed at the individual level, this theory has been extended to the organizational level [28]. TPB is based on the premise that an actor's behavior can be inferred from behavioral intention, which depends on attitudes, subjective norms, and perceived behavioral control [28]. TPB provides parsimonious predictions and explanations of adoption behavior from a social-psychology perspective, which can be used to support this research from a multi-stakeholder perspective.

TABLE 1. Blockchain adoption categories in the engineering-construction industry determined from the literature analysis.

Category	Factors	Typical literature
Technological benefits and traits	Benefits (operation and management efficiency enhancement, cost reduction, transparency and relationship improvement, integration and collaboration enhancement) and traits (complexity, compatibility, and cost)	[11], [21], [5], [6], [20]
Organizational conditions	Capital, expertise, employees' attitude toward blockchain technology, management resources, and technical information resources.	[10], [23], [20]
External environment	Supply chain network (such as clients, partners, and peer projects) and institutional network (such as governments, academic communities, industry associations, and software vendors)	[24], [25]
Decision layer features	Top-managers' experience, risk preference, support and commitment, knowledge and attitude toward blockchain technology, social and psychological traits	[10], [20]

Moreover, an extension of TPB (by identifying the concept of regulatory focus) serves as an indicator of the macro-level motivation of multiple stakeholders in this study. Higgins [29] distinguished two motivational dimensions that guide self-regulation activities: promotion-oriented aspirations and accomplishments, and prevention-oriented responsibilities and safety. The former explains individuals' attitudes and regulated behaviors to promote progress, growth, and achievement, whereas the latter forms individual attitudes and regulated behaviors to ensure safety and responsibility. Prior research shows that regulatory focus significantly impacts actors' attitudes and their tendency to engage in different courses of action. For example, Qian and Zhang [30] found that owners with promotion focus could trigger contractors' opportunistic behavior, whereas prevention focus has the opposite effect. Wang et al. [31] also discussed the different effects of promotion and prevention, focusing on megaproject uncertainty. However, the existing literature provides limited insight into the influence of regulatory focus on the intention to adopt blockchain technology.

C. MULTI-STAKEHOLDER PERSPECTIVE FOR BLOCKCHAIN ADOPTION IN THE ENGINEERING-CONSTRUCTION INDUSTRY

From a multi-stakeholder perspective, stakeholders can be described as organizations or individuals who play significant roles in a project and can affect project success or failure. Understanding and integrating the perspectives of diverse stakeholders is important to identify agreements and conflicts in their priorities, thereby benefiting the adoption and scaling-up of construction innovation [32]. Consequently, the multi-stakeholder approach has attracted attention in the industry. For instance, Law et al. [32] explored key factors for the adoption of construction robotics in Hong Kong by ranking the interests and concerns of various stakeholders. Won et al. [15] revealed that the roles of respondents can influence cloud computing adoption in the construction industry. Liao et al. [16] identified value-adding factors for BIM-based project activities and their delivery in Singapore from different stakeholder viewpoints.

Regarding studies involving blockchain adoption, the perspectives of multiple stakeholders have received little attention. This may hinder attempts to establish a robust understanding of the concepts and implications associated with blockchain adoption because stakeholders tend to experience different economic, social, and environmental conditions, resulting in significant differences in their judgment and behavior [33]. It remains unclear whether stakeholders share any similarities or differences when considering blockchain adoption factors. Therefore, in this study, three major types of project stakeholders in the Chinese engineering-construction industry were selected to assess any differences in adoption factors: owners, consultants, and contractors.

III. THEORETICAL FRAMEWORK AND RESEARCH HYPOTHESES

A. THEORETICAL FRAMEWORK

This study is exploratory, and semi-structured interviews were first conducted to capture the primary determinants. The TPB framework was then supplemented and modified based on interviews with three expert practitioners and two senior researchers in China. All participants held management positions with clear oversight and decision-making authority in their organizations and would, therefore, directly influence the adoption of blockchain technology. According to the interview guide, the interviews were conducted by brainstorming an initial set of open-ended questions, such as a description of the blockchain adoption process and key factors that motivate organizations to adopt blockchain technology.

The interviews verified that the factors driving blockchain adoption in this industry involve behavioral control, attitudes, and subjective norms. Attitudes are distinct in terms of perceived benefits and risks, originating from positive and negative attributes associated with blockchain technology. Attitudes toward blockchain technology involve cognitive processes that depend on pre-existing perceptions of its attributes, consistent with the connotations of behavioral attitudes [28] that describe actors' opinions and comments regarding different situations. Subjective norms are institutional pressures felt by construction organizations when deciding whether to adopt blockchain technology [34]. They reflect the influence of government, peers, competitors, and other external organizations on the adoption of blockchain technology by construction organizations.

Perceived behavioral control reflects an organization's ability to adopt a certain behavior [28]. In addition, a boundary condition for determining adoption intention was identified from the interviews. Based on these results, a theoretical framework is proposed, and the related concepts are refined into specific measurement variables.

B. HYPOTHESES DEVELOPMENT

1) INTENTION AND BLOCKCHAIN ADOPTION

Attitude predicts innovation adoption intentions and decisions, especially when decision makers must make rational decisions involving an important topic [35]. In the engineering-construction industry, key stakeholders tend to exhibit positive attitudes once they perceive the benefits of blockchain adoption. According to Bhat and Reddy [36], blockchain technology can generate both symbolic and functional benefits. Symbolic benefits derived from perceived strategic level benefits involve corporate image enhancement, reputation improvement, and gain in market share, whereas functional benefits focus on efficiency and relate to the extent to which a technology is useful to specific departments [37], businesses, and processes [38]. Stakeholders' adoption decisions usually follow the logic of cost minimization and efficiency maximization, as their main business goal is survival. Therefore, stakeholders tend to adopt blockchain technology only when they believe that its value increases potential benefits or satisfies the needs of their projects.

H1: Perceived functional benefits are positively associated with blockchain adoption intention (H1a) and blockchain adoption (H1b).

H2: Perceived symbolic benefits are positively associated with blockchain adoption intention (H2a) and blockchain adoption (H2b).

Despite potential benefits, blockchain adoption can lead to losses or risks. Perceived risks are subjective and represent possible losses that can occur during the implementation process [39]. High levels of risk perception can lead to delayed decisions and motivate stakeholders to engage in risk reduction efforts. First, the complexity of the technology and additional transaction costs associated with evaluating, building, and deploying blockchain systems may hinder blockchain adoption. Second, technical vulnerabilities are a major concern in new technology adoption [2], such as data security and privacy issues, architecture and design risks, private key management, and smart contract risks. Uncertainty is a dimension of risk related to the limited knowledge that a decision maker may have regarding a new technology [40]. Adopting virtualization technology can lead to increased concerns among organizational decision makers because of the invisible, undefined boundaries of virtualization technology and potential increased risks to data security and integrity [41]. The engineering-construction project implementation process includes sensitive information involving quotes and contract terms because engineering-construction projects typically involve large transaction amounts. Consequently, organizations may be reluctant to adopt blockchain technology in order to prevent their organizational data from being commingled with data from other companies or being accidentally disclosed to the public. Third, stakeholders in engineering-construction projects may only need to participate in project development occasionally, such that certain contracting parties may see no need to adopt blockchain technology as a long-term business model. The relationship between smart contracts and complex projects inevitably undermines attempts to secure the full benefits of the transactions involved in a construction project [6]. Relational discontinuities and additional coordination of transactions are costly to all parties involved in seeking to adopt blockchain technology [42].

H3: Perceived risk attitudes are negatively associated with blockchain adoption intention (H3a) and blockchain adoption (H3b).

Institutional theory focuses on organizations' institutional environments and how these influence behavioral and structural changes to gain social legitimacy [43]. Institutional pressure is perceived social pressure exerted by other important stakeholders when making decisions [44]. During the process of innovation technology adoption in the engineering-construction industry, perceived pressures are mainly associated with the government, partners, or peer companies [34], [45]. Institutional pressure includes normative, mimetic, and coercive pressures [46] that describe pressures corresponding to subjective norms. Therefore, pressures exerted by the external environment are considered to represent subjective norms. Normative pressure refers to the influence applied by organizations through internal values and standards [46]. Quasi-governmental organizations can help define and promulgate specifications for blockchain adoption by organizing workshops that promote the potential advantages of blockchain technology. Likewise, other organizations, such as software vendors and universities, can exert normative influence on construction stakeholders through professional training and certification [47]. As critical decision makers for blockchain adoption in engineering-construction projects, owners, contractors, and consultants can be potential focal points for these normative influences. Through communication with professionals, these decision makers can better understand the value and industry expectations when using blockchain technology in their projects, thus providing additional support for blockchain adoption. Coercive pressures are formal and informal pressures applied by other organizations that focus on rules, penalties, or incentives [46]. In engineering-construction projects, coercive pressure is likely to come primarily from regulatory agencies and industry associations. Mimetic pressures force enterprises to imitate the successful practices of other equivalent organizations. Stakeholders can learn from their peers to cope with the risk of uncertainty and gain economic benefits with minimal trial costs [34]. Uncertainty is the primary source of mimetic pressures. Although blockchain technology often involves complex processes and external factors in its operation, stakeholders may perceive that they are more

vulnerable to peer companies with similar characteristics and institutional environments regarding future projects if they do not adopt similar technology.

H4: Institutional pressures are positively associated with blockchain adoption intention (H4a) and blockchain adoption (H4b).

Next, perceived behavioral control describes the perceived difficulty or ease of implementing a certain behavior [48]. The more favorable the resource conditions an organization has and the fewer the expected barriers, the stronger the perceived control over the organization's behavior [49]. The need for blockchain technology in the engineering-construction industry stems from the activities of stakeholders; therefore, its adoption requires organizations to not only have the appropriate configuration of resources (e.g., infrastructure, workforce, capital), but also the ability to control and transform them [44]. To adopt blockchain technology successfully, stakeholders must change past practices and formulate a new approach or system, which will lead to more complicated practices [6]. Therefore, stakeholders are inclined to adopt blockchain technology only when they can confidently expect more control over these factors. Blockchain adoption intention and actual adoption can be enhanced when stakeholders believe that future behavior can be effectively controlled.

H5: Perceived behavioral control is positively associated with blockchain adoption intention (H5a) and blockchain adoption (H5b).

Finally, adoption intention reflects the extent to which a decision maker wishes to engage in a behavior, or how much effort the decision maker is willing to commit toward achieving that behavior. Based on the TPB context, adoption intention can predict technology adoption and mediate the relationships among attitudes, subjective norms, perceived behavioral control, and technology adoption [35]. Many organizational studies have validated the role of blockchain adoption intention. For example, Yuan et al. [50] explored the predictors of project managers' waste reduction intentions and concluded that attitude was the strongest predictor, followed by subjective norms and perceived behavioral control. Wang et al. [49] found that adoption intention mediates the determinants affecting technology adoption. The results obtained by Li et al. [51] strongly support the TPB model in predicting contractor employees' construction waste reduction intentions and behavior. Therefore, the intention to adopt blockchain technology can mediate the relationships among these three factors and the adoption of blockchain technology.

H6: Blockchain adoption intention is positively associated with blockchain adoption.

H7: Blockchain adoption intention plays a mediating role in the relationships among value attitudes, institutional pressures, perceived behavioral control, and blockchain adoption.

2) MODERATION EFFECT OF REGULATORY FOCUS
Beyond the boundaries of the micro-level concept, regulatory focus also has the potential to shape organizational
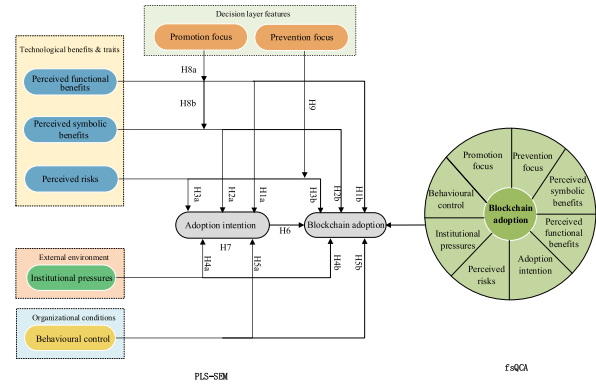

FIGURE 1. Theoretical framework.

characteristics [52]. Generally, most organizations' decisions are made by members of the top management group, and their personal preferences form regulatory focus, which relates to this study's requirements from the perspective of multiple stakeholders. Moreover, long-term corporate ideology and culture can influence a particular area of regulatory focus [52]. Therefore, regulatory focus may differ among stakeholders. Multiple stakeholders with transformational leadership and an open culture tend to favor promotion focus. In contrast, stakeholders with transactional leadership and a closed culture are likely to develop a prevention-oriented regulatory focus. Therefore, regulatory focus serves as the macro-level motivation for multiple stakeholders in the industry.

Regulatory focus in different situations can influence the perception, emotion, participation, and behavior of actors. Stakeholders with promotion focus are more likely to conduct self-efficacy assessments and persuade individuals to pursue their interests, whereas prevention-focused stakeholders will emphasize perceived risks and are more likely to persuade individuals from a loss-avoidance perspective.

H8: Promotion focus significantly moderates the relationship between perceived benefits (H8a-perceived functional benefits and H8b-perceived symbolic benefits) and blockchain adoption intention.

H9: Prevention focus significantly moderates the relationship between perceived risks and blockchain adoption intention.

Additionally, two broad propositions are made: not all predictors are expected to be necessary to influence the adoption of blockchain technology, and not all predictors are expected to be sufficient to influence blockchain adoption. Under these assumptions, a theoretical framework is proposed, as shown in Figure 1.

IV. METHODOLOGY
A survey approach was adopted to collect quantitative data using questionnaires. Figure 2 illustrates the research flow and methodology. First, a literature review and expert opinions were used to derive theories and factors contributing
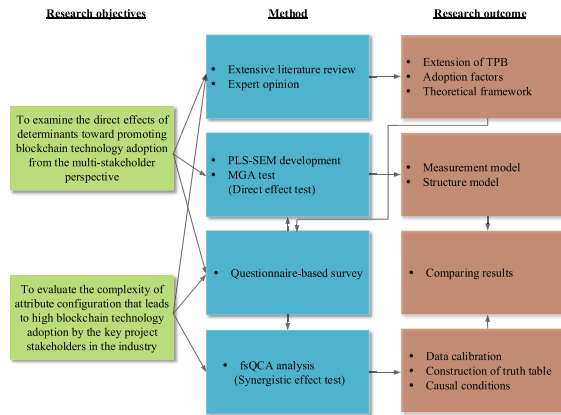
FIGURE 2. Research method.

to blockchain adoption. Subsequently, to assess the linear relationships and configuration effects of the variables, this study analyzed the data using two methods: PLS-SEM and fsQCA, respectively.

The reason for using the PLS-SEM method is that it has obvious advantages for the analysis of complex models and can deal with both formative and reactive conformations [53]. This study model not only contains both formative and reactive variables, but is also a complex model consisting of nine latent variables**;**hence, the PLS-SEM method is well suited for this exploratory study. Subsequently, the data were analyzed using fsQCA, a comprehensive analysis technique. The advantage of fsQCA is that (1) it acknowledges the existence of asymmetric relationships between causal relationships and assumes that multiple solutions may produce the same outcome [54]. (2) The fsQCA method includes causal complexity, meaning that not all conditions must be present to cause a particular outcome, and that different combinations of causal conditions may lead to the same outcome. The fsQCA approach complements the PLS-SEM approach by providing a more fine-grained interpretation of the research questions in this study [54].

A. MEASURES

There are few empirical studies on blockchain adoption and they mostly focus on the supply chain management domain. However, they still provide a reference for variable measurement of blockchain adoption in construction firms. In addition, empirical studies on the adoption of other technologies such as big data, cloud computing, IoT, smart contracts, construction robotics, 3D printing, and BIM also provide references for this study. The measurements were based on scales developed in the literature that have been tested in other industries. From this, variables pertaining to the institutional environment (eight items) [34], [55], perceived benefits (nine items) [56], [57], [58], [59], perceived behavioral control (four items) [44], perceived risks (four items) [60], adoption intention (three items) [61], moderating variable (eight items) [31], [52] and blockchain adoption [61] were

defined. To meet the research context, the measurements were modified after discussions with knowledgeable scholars and practitioners. Chinese professionals reviewed the scales from related fields to evaluate their suitability and clarity. Before initiating formal data collection, the questions were extensively pre-tested during the development of the theoretical framework. A total of 39 items were identified and used in the questionnaire, as listed in Table 2.

B. DATA COLLECTION AND SAMPLING

The survey was approved by the Institutional Review Board of Jilin University and was later developed and distributed through the wjx.cn online survey system. The target population was Chinese engineering-construction industry professionals representing consultants, contractors, and owners. A snowballing approach was used to collect questionnaires during a two-phase period: November 2021–January 2022, and January 2022–February 2022. Participants who were involved in or familiar with blockchain-enabled engineering-construction projects were selected during the first data collection phase. Initially, potential respondents were contacted through a blockchain information service provider listed on the blockchain information service filing system (https://bcbeian.ifcert.cn/index). The system lists 1440 blockchain-related service providers in China. Exploratory emails were also sent to companies that have adopted construction blockchain technology using contact information provided by acquaintances. All qualified participants were invited to forward the survey link to their peers in order to identify other eligible participants. A total of 157 valid questionnaires were obtained.

In the second phase, the target population of the questionnaire was participants interested in adopting blockchain technology, including owners, consultants, and contractors. Questionnaires were distributed to WeChat groups formed by professionals involved in conferences or forums that address blockchain-related topics. Similarly, the questionnaire started with a filter question, and a snowballing approach was adopted to obtain additional participants. In total, 174 valid questionnaires were collected in the second phase. Overall, 331 valid questionnaires were obtained, and the valid questionnaires represented 104 owners, 110 consultants, and 117 contractors.

The respondents were asked to answer questions based on their understanding of their company's adoption of blockchain technology, and respondents were asked to rate their agreement with questions based on a simple 5-point Likert-type scale ranging from "strongly disagree" to "strongly agree." Table 3 summarizes the respondents' demographic characteristics. The Kolmogorov–Smirnov test was used to examine the sample distribution of the early and late respondents to test for nonresponse bias. The results of the sample distributions did not differ statistically, indicating that there were no issues regarding nonresponse bias.

TABLE 2. Measurement items.

Constructs	Measurement items
Perceived functional benefits (AE)	AE1: My firm expects blockchain technology to help improve operations and management efficiency.
	AE2: My firm expects blockchain technology to help reduce construction costs.
	AE3: My firm expects blockchain technology to help improve transparency and relationships among partners.
	AE4: My firm expects blockchain technology to help improve integration and collaboration.
	AE5: My firm expects blockchain technology to help improve construction payment processes.
Perceived symbolic benefits (AF)	AF1: My firm expects blockchain technology to help increase influence among peers.
	AF2: My firm expects blockchain technology to increase market share.
	AF3: My firm expects blockchain technology to enhance reputation.
	AF4: My firm expects blockchain technology to acquire recognition among peers, shareholders, and government.
Coercive pressures (IA)	IA1: It is important for my firm that government requires our projects to use blockchain technology.
	IA2: It is important for my firm that industry associations require our projects to use blockchain technology.
Normative pressures (IB)	IB1: It is important for my firm that our customers strongly advocate the adoption of blockchain technology in projects.
	IB2: It is important for my firm that software vendors strongly advocate the adoption of blockchain technology in projects.
	IB3: It is important for my firm that government strongly propagates the value of blockchain technology in projects.
	IB4: It is important for my firm that industry associations strongly propagate the value of blockchain technology projects.
Mimetic pressures (IC)	IC1: It is important for my firm that peer projects that have adopted blockchain technology have benefitted greatly.
	IC2: It is important for my firm that peer projects that have adopted blockchain technology have gained good reputation.
	IC3: It is important for my firm that peer projects that have adopted blockchain technology are perceived favorably by others.
Blockchain adoption intention (AD)	AD1: My firm intends to use blockchain technology if possible.
	AD2: My firm collects information about blockchain technology with the possible intention of using it.
	AD3: My firm has conducted a pilot test to evaluate blockchain technology.
Perceived behavioral control (CO)	CO1: My firm would be able to use blockchain technology well.
	CO 2: Using blockchain technology is entirely within our firm's control.
	CO 3: My firm has the resources, knowledge, and ability to use blockchain technology.
Perceived risks (PR)	PR1: There is much uncertainty as to whether the proposed benefits of blockchain technology would materialize if my firm was to utilize the technology.
	PR2: The level of overall risk in utilizing blockchain technology for our firm is very high compared to conventional methods.
	PR3: My firm is concerned that blockchain technology would not meet the quality that is expected.
	PR4: There is too much at stake in our business to use blockchain technology on a project.
Blockchain adoption (GH)	GH1: My firm invests resources in blockchain technology.
	GH2: Business activities in our firm require the use of blockchain technology.
	GH3: Functional areas in my firm require the use of blockchain technology.
Promotion focus (PF)	PA1: My firm makes decisions based on the principle of maximizing success.
	PF2: My firm can keep pace with industry trends.
	PF3: Our firm culture emphasizes constant change and development.
	PF4: My firm can break conventional rules to achieve our aims.
Prevention focus (PA)	PA1: When the corporation is in sound operating condition, my firm tends to maintain the status quo and rarely make a major adjustment.
	PA2: My firm strictly implements our corporate internal regulations and rules.
	PA3: In the face of risks, my firm tends to take conservative strategies.
	PA4: My firm views avoiding loss (failure) as our guide to action.

V. RESULTS OF PLS-SEM
A. MEASUREMENT MODEL
The reliability and validity of the measurement model are indicated by Tables 4 and 5, respectively. Composite reliability (CR) was used to test the reliability of the measurement model (Table 4). All measurement models exceed the 0.7 limit, indicating adequate reliability [53]. The average variance extracted (AVE) was used to assess the convergent validity of the reflective constructs (Table 4). The indicators of all constructs exhibited a factor loading above 0.70, and the AVE values achieved a minimum threshold of 0.50, indicating their suitability [53]. The convergent validity of the formative constructs was tested using weights [62]. By analyzing the developed model using the repeated indicators approach, the results reveal that the three types of pressure are statistically significant ($p < 0.01$) and of positive sign (Table 5), which supports the second-order construct of institutional pressures. The discriminant validity was tested

TABLE 3. Demographic characteristics.

Measures	Items	Frequency	Percentage
Education	Specialists and below	9	2.72%
	Bachelor	171	51.66%
	Master and above	151	45.62%
Job position	Project manager	100	30.21%
	Department manager	136	41.09%
	Professional executive	63	19.03%
	Other	32	9.67%
Type of firm	Owner	110	33.23%
	Contractor	117	35.35%
	Consultant	104	31.42%
Location	Northeast China	14	4.23%
	East China	87	26.28%
	Middle China	21	6.34%
	North China	56	16.92%
	South China	85	25.68%
	Southwest China	68	20.54%

using the Fornell–Larcker criterion [63]. The AVE values of the six variables were lower than 0.90, indicating adequate

TABLE 4. Reliability indicators for full sample and sub-samples.

Constructs	Full sample		Sub-sample: owners		Sub-sample: contractors		Sub-sample: consultants	
	CR	AVE	CR	AVE	CR	AVE	CR	AVE
AE (Perceived functional benefits)	0.914	0.681	0.929	0.725	0.897	0.636	0.929	0.725
AF (Perceived symbolic benefits)	0.900	0.692	0.884	0.655	0.900	0.692	0.884	0.655
IA (Coercive pressures)	0.942	0.890	0.948	0.902	0.932	0.873	0.948	0.902
IB (Normative pressures)	0.916	0.783	0.915	0.783	0.925	0.805	0.915	0.783
IC (Mimetic pressures)	0.925	0.756	0.926	0.759	0.911	0.720	0.926	0.759
AD (Blockchain adoption intention)	0.921	0.796	0.915	0.783	0.916	0.784	0.915	0.783
CO (Perceived behavioral control)	0.901	0.695	0.888	0.665	0.896	0.684	0.888	0.665
PR (Perceived risks)	0.922	0.746	0.917	0.734	0.904	0.701	0.917	0.734
GH (Blockchain adoption)	0.918	0.789	0.930	0.817	0.893	0.735	0.930	0.817
PF (Promotion focus)	0.907	0.710	0.904	0.701	0.894	0.679	0.904	0.701
PA (Prevention focus)	0.919	0.739	0.917	0.734	0.915	0.729	0.904	0.703

Note: CR represents the composite reliability; AVE represents the average variance extracted.

discriminant validity. Overall, the measurement items fulfilled the reliability and validity requirements for the subsequent analyses.

Moreover, variance inflation factors (VIFs) were used to test multicollinearity. For each first-order variable, the test results indicate that all VIF values achieved the recommended levels, with the VIFs of the full dataset, owners, contractors, and consultants ranging from 1.788–2.783, 1.615–2.872, 1.641–2.988, and 1.742–2.980, respectively, all of which were below the maximum limit of 5 [64]. Regarding second-order variables, Table 5 reveals that all VIF values ranged from 1.052 (lowest) to 1.599 (highest). Therefore, collinearity was not a problem in this model. Furthermore, we checked for potential common method bias using Harman's Single Factor Test. The results show that the first factor accounted for 26.74%, 29.98%, 23.06%, and 24.21% of the total variances, all of which are less than 50%; therefore, there were no issues with common method bias in this study.

B. STRUCTURAL MODEL

The structural model is mainly assessed by the coefficient of determination (R^2), predictive relevance (Q^2), and the significance of path coefficients. The results (Figure 3) revealed that all R^2 values were >0.1. Similarly, Q^2 values of all endogenous structures were above zero, suggesting that the model has good predictive power. The goodness of fit (GoF) index also exceeded the "large" threshold level of 0.36 [65] (Full sample: 0.757; Owners: 0.694; Contractors: 0.748; consultants: 0.718).

The path significance levels were estimated by applying the bootstrapping method using 5000 subsamples. The results for the full sample dataset are summarized in Figure 3. Except for H2b, all hypotheses were confirmed.

The results of mediation analysis indicate that adoption intention mediated the association between perceived functional benefits and blockchain adoption ($\beta = 0.135$, $p < 0.001$) with the following intervals: (bias= −0.001; 2.5%=0.099; 97.5%=0.183), as well as the association between perceived symbolic benefits and blockchain adoption ($\beta = 0.125$, $p < 0.001$) with the following
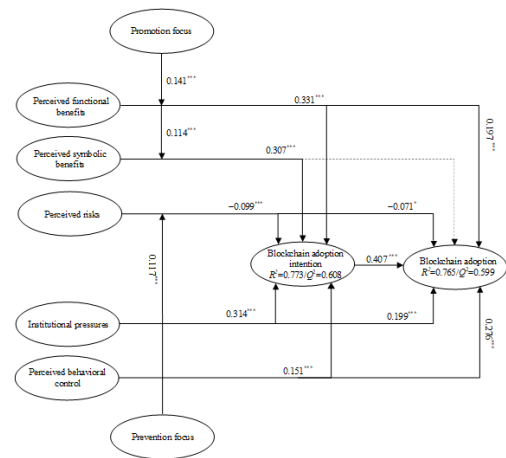

FIGURE 3. Structural model with main path coefficients.

intervals: (bias=0.000; 2.5%=0.086; 97.5%=0.176). Blockchain adoption intention mediated the association between perceived risks and blockchain adoption ($\beta = -0.040$, $p < 0.001$) with the following intervals: (bias=0.000; 2.5%= −0.067; 97.5%= −0.020). Blockchain adoption intention mediated the association between perceived behavioral control and blockchain adoption ($\beta = 0.061$, $p < 0.001$) with the following intervals: (bias=0.000; 2.5%=0.037; 97.5%=0.093). Blockchain adoption intention mediated the association between institutional pressures and blockchain adoption ($\beta = 0.128$, $p < 0.001$) with the following intervals: (bias= −0.002; 2.5%=0.093; 97.5% =0.176). Thus, **H7 is supported**.

To test the effects of regulatory focus, we constructed a standardized regression product term for the latent variable to analyze the moderating effects. Promotion focus significantly enhanced the association between perceived functional benefits, perceived symbolic benefits, and blockchain adoption intention ($\beta = 0.141$, $p < 0.001$ and $\beta = 0.114$, $p < 0.001$); therefore, **H8 is supported.** Moreover, prevention focus significantly enhances the association between perceived risks and blockchain adoption intention ($\beta = 0.117$, $p < 0.001$); thus, **H9 is supported**. A simple slope analysis

TABLE 5. Formative measurement model evaluation.

Formative construct	Constructs	Full sample		Sub-sample: owners		Sub-sample: contractors		Sub-sample: consultants	
		Weights	VIF	Weights	VIF	Weights	VIF	Weights	VIF
IN (Mimetic pressures)	IA	0.313***	1.463	0.290***	1.460	0.291***	1.299	0.290***	1.599
	IB	0.411***	1.378	0.397***	1.417	0.444***	1.270	0.397***	1.590
	IC	0.584***	1.156	0.566***	1.304	0.577***	1.178	0.566***	1.052

Note: VIF represents the variance inflation factors.

TABLE 6. Multi-group analysis test results for stakeholder differences between owners, contractors, and consultants (path differences).

| Path	Owners VS Contractors			Owners VS Consultants			Contractors VS Consultants		
	Diff	(WS) p	(P) p	Diff	(WS) p	(P) p	Diff	(WS) p	(P) p
H1a: AE→AD	0.057	0.439	0.437	0.320***	0.000	0.000	0.263***	0.001	0.000
H1b: AE→GH	−0.108	0.192	0.189	−0.136	0.064	0.064	−0.028	0.724	0.716
H2a: AF→AD	0.225**	0.008	0.007	−0.051	0.531	0.530	−0.276**	0.001	0.001
H2b: AF→GH	0.115	0.126	0.128	0.270*	0.018	0.019	0.155	0.150	0.143
H3a: PR→AD	0.100	0.144	0.140	0.068	0.266	0.261	0.033	0.632	0.630
H3b: PR→GH	0.154*	0.015	0.015	0.013	0.853	0.864	−0.031	0.073	0.078
H4a: IN→AD	−0.255***	0.003	0.003	−0.335***	0.000	0.000	−0.140	0.331	0.331
H4b: IN→GH	−0.052	0.552	0.547	−0.034	0.737	0.729	0.018	0.856	0.853
H5a: CO→AD	0.076	0.259	0.257	0.087	0.195	0.194	0.012	0.863	0.863
H5b: CO→GH	−0.336***	0.000	0.000	0.008	0.919	0.915	0.344***	0.000	0.000
H6: AD→GH	0.325**	0.005	0.004	−0.063	0.665	0.654	−0.389*	0.011	0.013
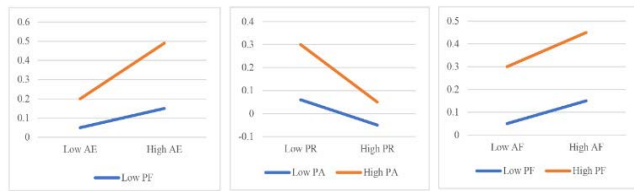
FIGURE 4. Decomposing the interaction effects: (a) AE × PF, (b) PR × PA, and (c) AF × PF.

was performed to test the moderating effect of blockchain adoption intention (Figure 4).

C. MULTI-GROUP ANALYSIS

To identify differences among the three sub-groups, .Henseler [66] multi-group analysis was performed. The outcomes in Table 6 show significant differences in the specific path coefficients between groups ($p < 0.05$). Five paths exhibit significant differences between owners and contractors. Accordingly, the positive effect of perceived symbolic benefits on blockchain adoption intention (Diff $\beta = 0.225$, $p < 0.05$) and blockchain adoption intention on blockchain adoption (Diff $\beta = 0.325$, $p < 0.001$) are much higher for owners than for contractors; however, the positive effect of institutional pressures on blockchain adoption intention ($\beta = -0.255$, $p < 0.05$) and perceived behavioral control on blockchain adoption ($\beta = -0.336$, $p < 0.001$) are much higher for contractors than for owners. Only three significant differences exist between owners and consultants in terms of perceived functional benefits ($\beta = 0.320$, $p < 0.001$) and the institutional pressures-blockchain adoption intention link ($\beta = -0.335$, $\rho = 0.000$) and the perceived symbolic benefits-blockchain adoption link ($\beta = 0.270$, $p < 0.05$).

The results indicate significant differences between perceived functional benefits and blockchain adoption intention ($\beta = -0.276$, $p < 0.001$), and between blockchain adoption intention and blockchain adoption ($\beta = -0.389$, $p < 0.05$) between contractors and consultants. However, the positive effect of perceived behavioral control on blockchain adoption ($\beta = 0.344$, $p < 0.001$) is much higher for contractors than for consultants.

VI. RESULTS OF FSQCA

The 3.0 software version of fsQCA was used to examine the configurations of the determinants of blockchain adoption based on the full sample. Moreover, three additional fsQCA estimations were implemented on the stakeholder category to study possible differences in blockchain adoption among stakeholders. First, the original data were converted into fuzzy membership scores on a 0–1 scale. Percentiles of 1, 3.5, and 5 were used to establish full non-membership, the crossover point, and full membership, respectively [67]. Next, a necessity analysis was performed to evaluate whether each antecedent condition was necessary to produce a particular outcome (i.e., high blockchain adoption). The results (Table 7) indicate that none of the antecedent conditions achieved the standard for the necessary conditions (consistency>0.9).

The final step of the fsQCA analysis was the adequacy analysis. A truth table was constructed to demonstrate possible combinations of causal conditions and their relationship with the outcome. The results (Table 8) indicate that each solution and the overall solution for all stakeholders or all three specific stakeholders had acceptable consistency (>0.80) and suitable levels of raw coverage (0.25–0.65). Therefore, because they surpass the necessary thresholds, the

TABLE 7. Analysis of necessary conditions for predicting blockchain adoption.

Factors	Full sample		Owners		Contractors		Consultants	
	Consistency	Coverage	Consistency	Coverage	Consistency	Coverage	Consistency	Coverage
AE	0.845	0.828	0.815	0.765	0.814	0.810	0.844	0.879
~AE	0.696	0.439	0.393	0.337	0.729	0.478	0.728	0.349
AF	0.824	0.823	0.735	0.773	0.787	0.791	0.876	0.854
~AF	0.359	0.359	0.359	0.345	0.744	0.493	0.766	0.344
IN	0.538	0.973	0.773	0.840	0.516	0.963	0.599	0.982
~IN	0.449	0.524	0.291	0.289	0.486	0.597	0.575	0.433
AD	0.848	0.925	0.858	0.907	0.798	0.907	0.885	0.931
~AD	0.261	0.261	0.261	0.252	0.660	0.449	0.620	0.300
CO	0.809	0.841	0.701	0.709	0.842	0.861	0.813	0.864
~CO	0.659	0.442	0.431	0.398	0.660	0.445	0.720	0.352
PR	0.586	0.736	0.475	0.490	0.630	0.744	0.518	0.793
~PR	0.779	0.631	0.632	0.597	0.862	0.642	0.766	0.539
PA	0.691	0.723	0.660	0.645	0.681	0.717	0.799	0.834
~PA	0.822	0.555	0.495	0.442	0.837	0.580	0.756	0.363
PF	0.782	0.770	0.494	0.498	0.756	0.761	0.693	0.838
~PF	0.748	0.475	0.652	0.599	0.779	0.517	0.777	0.429

TABLE 8. Solutions for promoting blockchain adoption considering multiple and individual stakeholders.

	Configuration	Raw coverage	Unique coverage	Consistency
Full sample				
Model S1 Achievement Decision Maker	S1: AE*AF*~IN*AD*PF*PA	0.426	0.079	0.970
Model S2 Enthusiastic Decision Maker	S2: AE*AF*AD*CO*PF*~PA	0.380	0.072	0.996
Model S3 Patchwork Decision Maker	S3: AE*~IN*AD*CO*~PR*~PF*~PA	0.254	0.024	0.997
Model S4 Cautious Decision Maker	S4: AE*AF*AD*CO*IN*~PR*PA	0.331	0.016	0.994
Model S5 Rational Decision Maker	S5: AE*AF*~AD*CO*~PR*~IN*~PF*PA	0.229	0.017	0.983
	Overall solution coverage: 0.586	Overall solution consistency: 0.971		
Owner				
Model W1 Cautious Decision Maker	W1: AE*~IN*AD*CO*~PR*PA	0.423	0.030	0.991
Model W2 Achievement Decision Maker	W2: AF*~IN*AD*PF*PA	0.467	0.046	0.974
Model W3 Conservative Decision Maker	W3: AE*AF*~IN*AD*CO*PA	0.444	0.010	0.991
Model W4 Enthusiastic Decision Maker	W4a: AE*AF*~IN*AD*CO*PF	0.475	0.027	0.992
	W4b: AE*AF*AD*CO*PF*~PA	0.329	0.007	0.994
	Overall solution coverage: 0.581	Overall solution consistency: 0.923		
Contractors				
ModelY1 Patchwork Decision Maker	Y1: AE*~IN*AD*CO*~PR*~PF*~PA	0.295	0.061	1
ModelY2 Futurist Decision Maker	Y2: AE*AF*IN*AD*~PR*PF*~PA	0.314	0.043	0.995
ModelY3 Achievement Decision Maker	Y3: AE*AF*~IN*AD*CO*PF*PA	0.380	0.056	0.992
ModelY4 Enthusiastic Decision Maker	Y4a: AE*AF*AD*CO*PR*PF*~PA	0.323	0.026	0.998
	Y4b: ~AE*AF*IN*AD*CO*PR*PF*PA	0.259	0.011	0.991
	Overall solution coverage: 0.544	Overall solution consistency: 0.990		
Consultants				
ModelT1 Achievement Decision Maker	T1: AE*AF*~IN*AD*PF*PA	0.403	0.057	0.977
ModelT2 Futurist Decision Maker	T2: AE*AF*AD*CO*~PR*PF	0.453	0.039	0.990
ModelT3 Cautious Decision Maker	T3: AE*AF*IN*AD*CO*~PR*PA	0.344	0.024	0.994
ModelT4 Enthusiastic Decision Maker	T4: AE*AF*IN*AD*CO*PF*~PA	0.334	0.026	0.997
	Overall solution coverage: 0.572	Overall solution consistency: 0.977		

results can yield a series of practical and methodological implications [68]. For further analysis, seven possible types of decision makers have been added and proposed based on the identified configurations and their characteristics. The first type of decision maker can be described as a Cautious Decision Maker, who focuses on the potential drawbacks of this emerging technology and engages in prevention focus. Next, the Achievement Decision Maker adopts a regulatory focus and considers the possible benefits of blockchain technology. The Conservative Decision Maker is characterized by the prevention focus approach and focuses on the

perceived risks without concern for benefits. The Patchwork Decision Maker primarily considers both risk and opportunity with respect to blockchain adoption. The Enthusiastic Decision Maker considers only positive factors, including functional and strategic benefits, perceived behavioral control, and engages in high promotion focus. The Futurist Decision Maker practices promotion focus, focusing only on expected positive benefits. Finally, the Rational Decision Maker has low adoption intention but demonstrates high perceived value and behavioral control, as well as low perceived risk.

Specifically, four new configurations were revealed to cover all key stakeholders in the full sample and each stakeholder individually in the analysis. The results involve five types of stakeholder adoption models or configurations: S1, S2, S3, S4, and S5. Additionally, the configurations at the project level were analyzed based on individual stakeholders. Four types of models (W1–W4) were found to lead to effective blockchain adoption by owners. Similarly, the results reveal four types of configurations for contractors, where the fourth model exhibited a similar pattern to the two sub-models, as observed in the owners' configuration analysis. Regarding consultants, the results show only four main models (without sub-models) for improving blockchain adoption.

VII. CONCLUSION

Based on a questionnaire survey applied to the Chinese engineering-construction industry, this study used PLS-SEM and fsQCA analysis methods to study the antecedents of blockchain adoption from a multi-stakeholder perspective.

First, the PLS-SEM results indicate that institutional pressures, perceived functional benefits, and behavioral control can directly trigger blockchain adoption. Although perceived symbolic benefits do not exert direct effects on blockchain adoption, their indirect effects are fully mediated by adoption intention. Promotion focus and prevention focus moderate the relationships between determinants and adoption intention. In addition, the PLS multi-group analysis found multiple path differences among different stakeholders.

Second, this study examined the configuration effect of the antecedents of blockchain adoption using the fsQCA analysis method. It was found that no single factor or its negation is the necessary condition to trigger blockchain adoption. Moreover, the configuration analysis results show four new configurations that trigger blockchain adoption by considering (a) all stakeholders as a group, and sub-groups consisting of: (b) owners, (c) contractors, and (d) consultants.

Overall, the antecedents for blockchain adoption are complex. This study not only reveals the linear, nonlinear, heterogeneous, and dynamic interactions that shape the antecedents of blockchain adoption but should help in the application and promotion of blockchain technology through implementing targeted strategies for specific stakeholders.

A. THEORETICAL CONTRIBUTIONS

First, this study provides a new theoretical and empirical understanding of the intermediary and moderating mechanisms affecting blockchain adoption in the engineering-construction industry. The findings using PLS-SEM are also partly supported by the TPB literature regarding attitude behavior and social environment factors that enhance blockchain adoption in the engineering-construction industry [2]. Moreover, this research divides perceived benefits into two new dimensions to better reflect the attitudes of construction companies toward blockchain adoption. Hence, this study also extends TPB theory by improving the explanatory context.

More importantly, in response to the need for studies involving multi-stakeholder perception, this study uses the PLS multi-group analysis method to examine sub-samples representing owners, contractors, and consultants, which enriches the multi-stakeholder research literature. The multi-group analysis reveals that perceived functional benefits are more important to owners and consultants than to contractors. In contrast, symbolic benefits are more important to owners and contractors than to consultants. A possible reason for this may be because of their different goals. Contractors' goals are usually short-term and specific and focus more on improvements in project quality, duration, and cost [32]. In addition, they lack social responsibility and strategic vision owing to their generally small size and low social impact [51]. Institutional pressures were found to foster blockchain adoption among contractors and consultants, but not among owners because of the unimportance of institutional pressures, which can be attributed to the dominance of owners and the lack of laws and regulations that specifically apply to blockchain projects [6]. Perceived behavioral control was the most influential factor among contractors. A reasonable explanation is that as key performers in project execution, contractors are required to complete complex tasks under contract throughout the project lifecycle [69], and thus place more emphasis on resource and capacity requirements than other construction sectors. This study can arguably be considered to be the first multi-stakeholder study in the engineering-construction field. The findings reveal distinct and meaningful inferences that consider the perspectives of multiple stakeholders with respect to new technology adoption [13].

The fsQCA results complement the analysis of net effects by providing further insights that contribute to a deeper understanding of the complex causal patterns of blockchain adoption antecedents. PLS-SEM and fsQCA results yielded several consistent outcomes. For example, adoption intention mediates the relationship between determinants and blockchain adoption in the PLS-SEM analysis. The fsQCA results reveal that adoption intention can be considered a core condition for adoption, as it is present in all solutions. However, some contradictory findings have also been discovered: the absence or negation of some positive determinants surprisingly leads to more positive adoption decisions, whereas the presence of some negative determinants may lead to similar results, depending on their association with other configurations. Overall, these findings support the assertion that blockchain adoption is a complex phenomenon.

B. MANAGERIAL IMPLICATIONS

From a cross-organizational perspective, this study provides comprehensive practical guidelines for governments, blockchain technology providers, and businesses to enhance blockchain adoption by owners, contractors, and consultants. Specifically, blockchain technology promoters can differentiate blockchain technology recommendations suited

to different stakeholders based on their personalities. For owners, improving perceived benefits and reducing perceived risks can be a strategic guide for blockchain technology development and promotion. For example, suppliers should consider marketing strategies to highlight technological advantages and low risks, and software vendors should fundamentally improve their technical and service capabilities to improve technological advancement and service standardization. Moreover, they should strengthen the stability, security, and usability of the blockchain infrastructure and focus on developing an easy-to-use platform. Focusing more on institutional pressures and perceived behavioral control is essential for contractors. For example, suppliers should improve the experience and capabilities of contractors by providing after-sales services such as knowledge training, and the government should adopt policies such as providing subsidies to contractors to reduce the cost of blockchain adoption. For consultants, the focus should be on strengthening their intentions and institutional pressures toward blockchain adoption. This type of improvement requires industry institutions to exert normative influence on construction companies and the government to create best practices and highlight successful experiences involving blockchain technology. The configurations presented in this paper allow all stakeholders or specific stakeholders to select the most appropriate way to improve blockchain adoption attitudes and behaviors.

C. LIMITATIONS AND FUTURE RESEARCH

This study has some limitations, as only owners, consultants, and contractors are considered in exploring the determinants of blockchain adoption and other participants in engineering-construction projects, such as suppliers, manufacturers, and designers, are excluded. Therefore, future studies should consider these participants to extend and enrich the conclusions of this study. Moreover, data from other countries will need to be collected to compare and expand the research results in the future.

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