Framework for a Blockchain-Based Infrastructure Project Financing System

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ABSTRACT Infrastructure is the lifeline for fulfilling most of the basic needs that support the well-being and prosperity of human society. To sustain improvements in quality of life, China, as a developing economy, needs more and better infrastructure, despite facing massive funding shortages. An enormous amount of its private capital is locked up because of the many obstacles to private investment. This study introduces a blockchain-based financing instrument for unlocking massive private capital to fund infrastructure projects in China. It draws on a literature review and expert survey to identify the major holdups preventing private capital from funding infrastructure projects and to compare the existing instruments used in infrastructure financing. A fuzzy AHP-SWOT analysis is conducted to reveal the main internal factors (strengths and weaknesses) and external factors (opportunities and threats) in using blockchain-based finance in infrastructure projects. Finally, a conceptual framework for a blockchain-based infrastructure financing system is formulated to take advantage of the strength and opportunities, meanwhile, counter the weakness and threats, and the framework is also validated through its deployment on Hyperledger Fabric.

INDEX TERMS Blockchain, fuzzy AHP, Hyperledger Fabric, infrastructure projects, project finance, SWOT.

I. INTRODUCTION

Infrastructure is the lifeline of a region and forms its nexus with the quality of life of individuals and society [1], [2]. For instance, highways and high-speed railway networks have stimulated regional economic development and integration, bringing greater convenience to the people who live there [3]. Mega infrastructure projects, including the Qinghai–Tibet Railway, West–East Gas Transmission, West–East Electricity Transmission, and South-to-North Water Diversion projects, have narrowed the economic gaps between different regions by engaging the resource advantages of the central and western regions [2]. These projects play an important role in strengthening national unity, maintaining social stability, and consolidating national security. However, China’s continuing enormous demand for infrastructure is not matched by the funds available [4], [5], which creates a bottleneck restricting the country’s economic growth rate [6]–[8].

According to McKinsey, in 2015, global infrastructure spending was $9.5 trillion, accounting for 14% of global GDP [9]. It is estimated that by 2035, annual world infrastructure investment will have reached an average of $3.7 trillion, which represents a funding gap of $5.5 trillion; for China, that gap is expected to reach $2.5 trillion [9]. Total investment in fixed assets in China’s municipal infrastructure increased from $202 billion in 2011 to $290 billion in 2017. In terms of funding sources, China’s infrastructure construction funds are still dominated by self-raised funds (25.36%), local government financial allocations (27.74%), and bank loans (25.31%). The proportion of bonds has recently increased but remains low. Notably, dependence on local government fiscal revenue and expenditure has increased, with the proportion of local fiscal expenditure rising from 85.2% in 1994 to 85.2% in 2018. With this continuous deterioration, pressure on the solvency of local governments has risen to an alarming level, and new sources of funding are required.
In order to address the funding gap without increasing fiscal pressure [10], the government’s financial department, which is the traditional primary sponsor of infrastructure, is seeking private capital to fund infrastructure projects [11], [12]. Against a background of low long-term interest rates, infrastructure financing is a very profitable investment opportunity for private capital [11]. However, because of the risks associated with laws, policies, and the market [11], [13], [14], a large amount of private capital has not been invested in infrastructure construction, and has instead flooded into the real estate industry. The consequences of this have been undesirable, with speculation in housing prices, imbalanced supply and demand structures, and a large proportion of investment-oriented housing purchases. Accordingly, channeling private capital into the infrastructure industry is a priority for China.

Infrastructure financing is a serious problem that can have a major impact not only on the project in question but also on society as a whole, and scholars have sought ways to surmount the obstacles in this area. Ferrari et al. [13] explored the risks associated with the different phases of infrastructure projects, confirming the unmet demand for financing and insufficient supply of private capital. Gundes et al. [15] carried out a systematic review of the literature on financial issues affecting construction firms. Li et al. [10] proposed a project bond and credit default swap mechanism for financing infrastructure projects under public-private partnership (PPP) arrangements. Lu et al. [16] developed an assessment framework for an asset-backed securitization financing instrument for infrastructure projects in the same context. Sainati et al. [12] classified the types and functions of special purpose vehicles (SPVs) in mega infrastructure projects. Tian et al. [17] proposed a preliminary conceptual framework for infrastructure tokenization.

Blockchain technology, a decentralized ledger database for recording transactions [18]–[20], can revolutionize many aspects of the financial services sector and the broader economy by eliminating intermediaries, automating transactions across organizations, and widening access to finance [21]–[22]. Blockchain-based tokenization of infrastructure assets, which is the digitalization of real assets or financial instruments through blockchain technology, can address some of the fundamental challenges in infrastructure financing, including illiquidity, high transaction costs, and lack of transparency [13], [21]–[23].

Previous research has identified the potential advantages of blockchain technology, but so far there has been no empirical study of the challenges of infrastructure financing in China and no framework that is implementable in practice. Hence, this study proposes a framework for a blockchain-based infrastructure financing system validated using the Hyperledger Fabric platform on the basis of a fuzzy AHP-SWOT analysis of the internal and external influential factors. The aim is to answer three main questions: What challenges does private capital face in infrastructure financing in China? What internal and external factors influence blockchain-based infrastructure financing? How can blockchain be used to channel significant amounts of private capital into the infrastructure industry?

The following of this paper is organized as follows: section II presents some challenges faced in the infrastructure finance in China; section III introduces the existing financing instruments and performs a comparative analysis; section IV outlines the research design; results of a fuzzy AHP-SWOT analysis on the influencing factors on the success of blockchain-based finance for infrastructure projects in China is presented in section V; as a result, a conceptual framework for blockchain-based infrastructure finance instrument is proposed in section VI; then, the conceptual framework is validated through the Hyperledger platform VII; lastly, the paper wraps up with conclusions.

II. CHALLENGES IN INFRASTRUCTURE INVESTMENT AND FINANCING

A. INCOMPLETE LEGAL PROTECTION FOR PRIVATE INVESTORS

Infrastructure projects span a wide range of industries and regulatory contexts. Existing laws and regulations are incomplete, and the rights and obligations of the government and private investors are not clearly stipulated. The vagueness and ineffectiveness of government commitments can prevent private investors from financing infrastructure projects [11]. For example, in one city, it was anticipated that an infrastructure project would use the BOT financing model. However, because of a change of mayor, the project company was forced to renegotiate its contract with the government, resulting in the suspension of the project and serious economic losses to private investors, who did not benefit from appropriate legal protections.

B. LOW RATE OF LONG-TERM RETURN ON INVESTMENT

Infrastructure projects typically generate cash flow several years to decades after their initiation. During this period, many factors, such as low liquidity, result in relatively high risks and costs for private investors [11]. For example, according to China’s PPP project database, the average rate of return on PPP projects is 6–8%, and the average operation period is 20 years. In addition, the risks associated with government default and uncertain return on investment have discouraged private companies and small-scale investors in some regions.

C. HIGH THRESHOLD FOR PRIVATE CAPITAL INVESTMENT

Infrastructure projects, such as highways and high-speed railway, are usually capital-intensive. Most infrastructure projects are local strategic investment projects that are critical for governments because of their impact on livelihoods. To work on these projects, contractors are required to have strong financial and technical capabilities; in practice, only state-owned enterprises or large-scale private enterprises are

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suitably qualified. As a result, infrastructure assets are mainly controlled by local government- or state-owned enterprises [11], and there is a significant barrier for small and medium private investors seeking to fund infrastructure projects. According to statistics from the Bureau of Finance in China, at the end of 2019, private capital accounted for only 33.7% of all PPP projects nationwide, which is low in comparison to the real estate industry.

D. MULTIPLE PARTICIPANTS AND HIGH RISKS
Because many stakeholders are involved in infrastructure projects, their relationships are complicated. For a long time, bank loans have accounted for the bulk of infrastructure project funding sources, and the proportion of equity financing is low, which creates information asymmetry. Based on government credit guarantees, banks and other financial institutions are in many cases willing to provide loans. The larger the project, the higher the risk, and the greater the cost of government borrowing. In case of project failure or abandonment, all the risk is likely to be borne by the private investors. Hence, when private capital finances infrastructure projects, unless there is a reasonable and transparent risk-sharing arrangement, a crisis of cooperation is likely [24]–[25].

E. PUBLIC DISTRUST OF PRIVATE CAPITAL INVESTMENT
During the implementation and operation of infrastructure projects by private entities, information opacity and frequent accidents have prompted distrust from the general public. For example, the construction of a new highway will destroy the original ecological environment, and the operation of a chemical plant will cause environmental pollution. Thus, people have an aversion to infrastructure projects funded by private capital, and this translates into deep-rooted distrust of particular types of projects. For example, PX (xylene) chemical projects in several big cities, such as Chengdu, Xiamen, and Maoming, have been suspended because of protests by local residents.

III. EXISTING INFRASTRUCTURE FINANCING INSTRUMENTS
In addition to traditional bank loans and government financial appropriations, other financing tools for infrastructure financing are available. Their advantages and disadvantages in the context of infrastructure projects are summarized in Table I.

A. SYNDICATED LOANS
Syndicated loans usually involve a group of banks that borrow from a single borrower. This method is used for debt financing in mega projects, because syndicated loans spread the huge risks of a single project among multiple banks. However, as syndicated loans account for most of the borrowings, the financing channels are limited [12].

B. ASSET SECURITIZATION
Asset-backed securities (ABS) are securities that are mortgaged by the loan assets of infrastructure projects [26]. On the one hand, asset securitization provides investors with an opportunity to spread risks and diversify revenue-generating asset portfolios with a premium on investment income. On the other hand, the conversion of illiquid assets into cash enhances liquidity of assets, which attracts investors. However, due to the large number of projects in the asset pool, the financing process is lengthy, complex, and low in transparency [14].

C. PROJECT REVENUE BONDS
Project revenue bonds are often used to raise funds for public welfare infrastructure projects. The bond term covers the project investment period, the construction period, and the operation period. The funds in the project flow in a closed environment, but the risks at different stages are quite different. Investors generally wait until the end of the construction period before investing in project bonds; that is, they tend to invest in the operating period, when the project has started to generate stable returns. In addition, investors have limited ability to assess project risks and tend to rely on external rating agencies.

D. SPECIAL LOCAL GOVERNMENT BONDS
Special local government bonds are issued to raise funds for the construction of major public welfare infrastructure projects. These bonds use the proceeds of the project to repay the debt and are issued in the name of the provincial government. Thus, they have a certain degree of credibility, although the revenue and expenditure are not directly included in the government budget. Bonds of this type not only relieve financial pressure on the government but also allow investors to enjoy tax exemptions on interest income. However, they are still characterized by small issuance quotas and mismatched maturity, which makes it difficult to meet financing needs. Moreover, the main bond issuer is the provincial government. If information is not disclosed in a timely manner, it is difficult to take account of the risks faced by lower-level government bodies, which leads to insufficient awareness of bonds by local governments and investors.

E. INFRASTRUCTURE EQUITY FUNDS
Infrastructure equity investment funds are private equity funds that raise private capital to invest in infrastructure project companies or project shares. These funds have strong liquidity, and this type of infrastructure investment meets the needs of institutional investors, such as social security funds and pension funds, whose long-term asset portfolio needs to align with the concession period (25–30 years) of the infrastructure projects. However, in recent years, due to the lack of project data and the tendency of investors to invest in low-risk assets, infrastructure equity investment funds have been slow to develop.
IV. RESEARCH METHODS
This study employs a novel quantitative method in assessing the blockchain-based finance system for infrastructure projects and subsequently offers a framework for a blockchain-based infrastructure financing system for infrastructure projects, which is validated through Hyperledger platform. Specifically, this research uses SWOT analysis to assess the internal and external influential advantages and disadvantages in using a blockchain-based infrastructure financing system. However, SWOT analysis, although useful, is a qualitative technique and therefore not informative enough for the purpose of formulating strategies [33]. Accordingly, this study also uses the quantitative technique of analytical hierarchy process (AHP) [34] to rank the factors and overcome the quantitative restrictions [33]. Fuzzy numbers are used to express in quantitative terms the otherwise linguistic measurements widely used in pairwise comparisons to model experts’ subjective judgments and to offset any uncertainty associated with the experts’ perception [33].

Based on the fuzzy AHP-SWOT analysis, the greatest weakness and threats as well strength and opportunities are discovered so that a conceptual framework can be formulated to best counter the weakness and disadvantages, meanwhile, to take advantage of the strength and advantages. To be reliable, the proposed framework is validated through the Hyperledger platform by establishing a blockchain-based finance system to simulate the functionalities designed in the framework.

| Financing Instrument | Pros | Cons | Project Case |
|----------------------|------|------|--------------|
| Bank Loan [19]       | • Bank provides professional supervisory service | • Increased financial leverage | Chong-Jing Expressway project (Total loan: $1 billion) |
|                      | • Fast fundraising and large borrowing flexibility | • Exacerbation of the debt problem of local governments | |
|                      | • Quick response to project restructuring | • Long transaction settlement time | |
|                      | • Implicit guarantee for other investors | • Flawed integrity system and trust mechanism | |
| Credit Market        | • Dispersal of project risks and benefits | • High cost | Hangzhou–Qzhou Railway PPP project (Total loan: $22 billion) |
| Syndicated Loan [27] | • Large loan amount | • Confined financing source [28] | |
| Asset-Backed Securities [29] | • Long-term loan | • Poor credit penetration of the asset pool | Guangzhou Airport Expressway Vehicle Toll Revenue Right special plan (Total issuance: $647 million) |
|                      | • Reduced investment restrictions | • Long and complex financing process | |
|                      | • Dispersal of risks | • Lack of information and data | |
|                      | • Reasonable revenue plan | | |
|                      | • Stock assets revitalization and liquidity enhancement | | |
| Bond Market          | • High degree of standardization and liquidity | • High degree of risk | Waste Incineration Power Generation project of the Guangzhou Fourth Resources Thermal Power Plant (Bond quota: $117 million) |
| Special Local Government Bond [31] | • Closed operation of cash flow | • Reliance on external rating agencies | Smart Street Light project in Tianfu New District, Meishan (Bond quota: $162 million) |
|                      | • Easing of government financial pressure | | |
|                      | • Incentive to investment and an open capital pool | • Small issuance amount and mismatched maturity | |
|                      | • Tax deductions and subsidies for infrastructure investors | • Unclear positioning | |
| Equity market        | • Strong liquidity | • Lack of project data | Wuhan Metro Line 11 (Total: $221 million) |
| Infrastructure Equity Fund [32] | • Ability to raise scattered private capital | • Large project differences | |
|                      | • Facilitation of the financing of new projects | • Low-risk preference of investors | |
|                      | • Long-term asset allocation requirements matched with a long concession period | | |

TABLE II
SUMMARY OF SURVEY RESPONDENTS’ INFORMATION

| Category                  | Item                | Frequency | Proportion |
|---------------------------|---------------------|-----------|------------|
| Sex                       | Male                | 22        | 62.9%      |
|                           | Female              | 13        | 37.1%      |
| Company Type              | Owner               | 5         | 14.3%      |
|                           | Contractor          | 3         | 8.6%       |
|                           | Design Professional | 9         | 25.7%      |
|                           | Consultant          | 2         | 5.7%       |
|                           | Financial Institution| 6        | 17.1%      |
|                           | Tech Company        | 3         | 8.6%       |
|                           | University/Research Institute | 2 | 5.7% |
|                           | Government Agency   | 4         | 11.4%      |
|                           | Other               | 1         | 2.9%       |
| Job Title                 | Regional Manager    | 5         | 14.3%      |
|                           | Department Head     | 8         | 22.9%      |
|                           | Financial Manager   | 4         | 11.4%      |
|                           | Project Manager     | 7         | 20.0%      |
|                           | Senior Engineer     | 5         | 14.3%      |
|                           | Others              | 6         | 17.1%      |
| Work                      | Over 20 years       | 9         | 25.7%      |
|                           | 16–20 years         | 2         | 5.7%       |
|                           | 11–15 years         | 5         | 14.3%      |
|                           | 6–10 years          | 5         | 14.3%      |
|                           | 1–5 years           | 10        | 28.6%      |
|                           | Less than 1 year    | 4         | 11.4%      |
A. IDENTIFICATION OF INFLUENTIAL FACTORS

Drawing on SWOT analysis, this study first extracted the internal and external influential factors through literature analysis and then used a survey instrument to collect expert opinions on those factors (see Fig. 1). For credibility, a snowballing process was used to select a group of 35 recognized experts with various levels of managerial responsibilities and from diverse backgrounds (infrastructure, financial, and IT industries, and government departments) with an average of 10 years’ experience (see Table II). The experts were asked to give their ratings on a Likert scale because a large number of factors would make pairwise comparisons difficult and undermine the accuracy of the results.

B. INFLUENTIAL FACTORS ANALYSIS

1) FUZZY COMPARISON MATRIX

In the fuzzy AHP analysis, the first step was to obtain a comparison matrix using the questionnaire designed in accordance with the SWOT analysis (see Fig. 1). When formulating a mathematical model for practical problems, the triangular numbers are typically used for the sake of simplicity. The rating scale for the factor (criteria) comparison is presented in Table III; it was drawn from the membership functions for triangular fuzzy numbers in (1). The averaging method was used to aggregate the experts’ responses, and four matrices of pairwise comparison were formed (see Tables IV–VII).

2) WEIGHT CALCULATION AND CONSISTENCY RATE ANALYSIS

On the basis of the above formulas and comparison matrices, the local weights of the criteria (SWOT analysis factors) were obtained by implementing calculations based on (6) and then de-fuzzifying according to (7)–(9). The processes were conducted in Matlab 2020a and are shown in the last column of Tables III–VI.

\[ D_i^k = \sum_{j=1}^{n} a_{ij}^k + \left( \sum_{l=1, 2, 3, \ldots, n}^{n} a_{li}^k \right) \quad i = 1, 2, 3, \ldots, n; \quad j = 1, 2, 3, \ldots, n \]

\[ V(M_1 \geq M_2) = \sup_{x \geq y} \min (u_{M_1}(x), u_{M_2}(y)) \]

\[ (M_1 \geq M_2) = \begin{cases} \frac{1}{m_1 - u_1 - (m_2 - l_2)} & m_1 \geq m_2 \\ 0 & \text{otherwise} \\ \end{cases} \]

\[ D_i^k \]

represents the initial weights of the kth level criteria (e.g., SWOT analysis factors). \( a_{ij}^k \) denotes the fuzzy number of the ith factor at the kth level. \( \sup \) indicates the lower bound value or the minimum value. \( x \) and \( y \) stand for the fuzzy numbers.

Consistency analysis was conducted for the comparison matrices of each factor, all of which showed a good consistency rate (CR). For example, the CR value of the comparison matrix for the strengths group was 0.0808 < 0.1, suggesting consistent ratings. The local weights in the last column of Tables III–VI indicate the relative importance of the factors at the corresponding level of the AHP hierarchy shown in Fig. 1. The global weights were calculated by normalizing all the local weights (see Fig. 1).

C. Framework for blockchain-based finance system and validation

According to the findings of fuzzy AHP-SWOT analysis, this research formulates a conceptual framework for blockchain-based infrastructure finance system to take full advantage of the strength and opportunities identified, at the same time, it is designed to evade the weaknesses and threats faced by blockchain-based infrastructure finance system in China in comparison to the existing financing instruments. To achieve the objectives, the framework design places great emphasis on the alignment in the concept of blockchain and the procedure of infrastructure finance and the major participants in the process. It defines the major nodes of the blockchain system by identifying the primary participants in the infrastructure project financing in China and their relationships in accordance with the practice. After that, the framework is validated through its deployment in the Hyperledger Platform.

V. RESULTS

The major problems associated with the emerging financing tools for infrastructure projects concern low asset transparency [14], lack of data [13], and high transaction costs [11], [14], [35]. Proper use of blockchain technology is expected to relieve the...
current predicament while providing a new model for infrastructure investment and financing.

![Fuzzy AHP-SWOT analysis hierarchy structure.](image)

**FIGURE 1.** Fuzzy AHP-SWOT analysis hierarchy structure.

### TABLE IV

**FUZZY PAIRWISE COMPARISON MATRIX FOR STRENGTHS**

| Strength | S1       | S2       | S3       | S4       | S5       | S6       | Local Weight |
|----------|----------|----------|----------|----------|----------|----------|--------------|
| S1       | (1;1;1)  | (1/6;1/5;1/4) | (1/2;1/2) | (1/2;1/2) | (1/4;1/3;1/2) | (1/2;1/2) | 0.0849       |
| S2       | (4/5;6)  | (1;1;1)  | (4/5;6)  | (2;3;4)  | (1/2;1/2) | (4/5;6)  | 0.3579       |
| S3       | (1/2;1/2) | (1/6;1/5;1/4) | (1;1;1)  | (2;3;4)  | (1/4;1/3;1/2) | (1/4;1/3;1/2) | 0.0849       |
| S4       | (1/2;1/2) | (1/4;1/3;1/2) | (1/4;1/3;1/2) | (1;1;1)  | (1/4;1/3;1/2) | (1/2;1/2) | 0.0769       |
| S5       | (2;3;4)  | (1/2;1/2) | (2;3;4)  | (2;3;4)  | (1;1;1)  | (4;5;6)  | 0.3018       |
| S6       | (1/2;1/2) | (1/6;1/5;1/4) | (2;3;4)  | (1/2;1/2) | (1/6;1/5;1/4) | (1;1;1)  | 0.0936       |

Note: CR = 0.0808, S stands for strength.

### A. STRENGTHS

Table IV presents the ranking of the AHP sub-criteria in the strengths group in terms of their local weights. S2 (cost reduction) tops the list, followed by S5 (increased liquidity of the infrastructure asset). The weights of the remaining sub-criteria are approximately equal, suggesting that they are of equal importance. These results are in line with the literature on blockchain-based financing.

1) **DATA TRANSPARENCY AND SHARING**

Blockchain technology has great advantages in infrastructure project financing in terms of voluminous transaction information, strict security requirements, and the stakeholders’ need for cooperation and coordination [36]–[38]. Blockchain, a database that is decentralized and distributed, promotes information-sharing in a transparent manner and provides a platform for the analysis of decentralized big data. On the blockchain system, information is updated in real time, remaining safe and traceable, to achieve asset information penetration and eliminate information asymmetry between seller and buyer [36]–[40]. The distributed ledger enables all project participants, including the government, SPV, banks, exchanges, and investors, to access the same project information and jointly manage the flow of funds and the progress of the project [37]. This allows considerable administrative resources to be reserved for supervision, and the financial departments of government, project stakeholders, and other government agencies can monitor and review projects in real time [37], [41].

2) **PROCEDURE OPTIMIZATION AND COST REDUCTION**

Research has shown that blockchain technology can reduce costs [37], [42], [43]. According to McKinsey, in the short term, 70% of the value associated with blockchain lies in cost reduction [44]. Blockchain-based on-chain records and smart contracts can complete audits or transactions objectively and automatically, reducing the human workload of uploading or downloading information and managing transactions, simplifying the process, and reducing errors...
or rent-seeking behavior, which effectively reduces the intermediate cost [45]. For instance, in the asset securitization of PPP projects, the transaction process involves initiators, asset management agencies, securities underwriting agencies, credit enhancement agencies, credit rating agencies, asset appraisal agencies, and investors; the asset information circulates among different institutions, which results in huge information transaction costs. If blockchain technology is applied to asset securitization, smart contracts can automatically manage infrastructure financing funds by logging new investment funds for projects, appropriating redemption funds owed to investors [22], and making asset information transparent and accessible. This improves the efficiency of information transactions between the various institutions and ensures the security and integrity of data through encryption algorithms. The transparency of the process and the real-time sharing of information can optimize the transaction flow and greatly reduce project financing costs.

3) LIQUIDITY IMPROVEMENT AND ELIMINATION OF FINANCING THRESHOLDS

The tokenization of infrastructure assets enhances liquidity, eliminates third-party institutions, lowers financing thresholds, and allows retail investors or small and medium private capital to participate in infrastructure investment and financing [37], [46]. Because of the huge amount of funds required for infrastructure projects, many investors cannot finance projects in the traditional sense, but the tokenization of assets offers them a new way to finance projects. Asset tokenization has also broadened financing channels for infrastructure [37]. For instance, the Swiss real coin (SRC) issued by Crypto Real Estate Ltd. can be purchased by investors using Bitcoin (BTC) or Ethereum (ETC). The SRC is issued as a perpetual subordinated interest-free bond. The company distributes the proceeds of the SRC initial coin offering (ICO) to Swiss commercial real estate assets (about 92% of the net proceeds) and to the development of the monitoring and investment assistant (MIA) (about 5%). The remaining 3% is used to pay the company’s operating expenses. Of the net rental income, 80% is reinvested in real estate.

The intrinsic value of tokens increases through the value created by asset management, as well as the reinvestment of rental income and software development profits. MIA, a blockchain real estate robot, provides data-based advice and automatic valuation models to monitor and predict the earnings of assets and to manage their sustainability and amortization. Each SRC holder has a say in proposed acquisitions and can vote on whether certain properties should be added to the portfolio. In this way, the technical thresholds for financing are lowered, and investors can rely on MIA data in decision-making. Although SRC has primarily been used for real estate properties, infrastructure assets have a lot in common with real estate.

4) INFORMATION IRREVERSIBILITY AND STRENGTHENING OF COMPUTING POWER

From a technical perspective, blockchain technology is reliable and secure [36], [37]. As an infrastructure project progresses, it generates massive transaction data and other critical information. Traditional central information-sharing institutions typically rely on a unified data management center built and maintained by a third party to store all project-related data. As a result, the requirements on the data center in terms of data-processing capabilities are high. If the center is attacked, all the data are at risk of being destroyed, tampered with, or lost [47]. In contrast, blockchain is a distributed ledger system, and the failure of a single machine will not affect the operation of the system. Blockchain technology also has stronger computing power, as distributed systems can use the total computing power of all the machines on the chain. Moreover, the public and private key encryption algorithms ensure the authenticity and immutability of all the project information [48]. Any party seeking to enter the system must prove their identity, and authentication information, once uploaded, cannot be tampered with [27], [49].

B. WEAKNESSES

In terms of local weight, the most important sub-criterion in the weaknesses group is W5 (lack of application cases), followed by W9 (high energy consumption) and W4 (uneven computing power). The other sub-criteria are close to each other in weight. These results indicate that policy uncertainty has a substantial influence on blockchain-based financing for infrastructure projects. Likewise, technical challenges and lack of legal support are the greatest obstacles for investors in that context.

![Image](https://example.com/figure.png)

**TABLE V**

| Weakness | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 | W9 | Local Weight |
|----------|----|----|----|----|----|----|----|----|----|--------------|
| W1       | (1;1:1) | (1/2;1:2) | (1/2;1:2) | (1/2;1:2) | (1/4;1:3;1:2) | (1/2;1:2) | (1/4;1:3;1:2) | (1/2;1:2) | (1/2;1:2) | 0.0750        |
| W2       | (1/2;1:2) | (1/1:1) | (1/2;1:2) | (1/4;1:3;1:2) | (1/6;1:5:1/4) | (1/2;1:2) | (2;3:4) | (1/2;1:2) | (1/4;1:3;1/2) | 0.0708        |
| W3       | (1/2:1:2) | (1/2:1:2) | (1/1:1) | (1/6:1:5:1/4) | (1/4;1:3;1:2) | (1/2;1:2) | (1/2;1:2) | (1/2;1:2) | (1/4;1:3;1/2) | 0.0627        |
| W4       | (1/2:1:2) | (2;3:4) | (4;5:6) | (1/1:1) | (1/2:1:2) | (2;3:4) | (2;3:4) | (1/2:1:2) | (1/2:1:2) | 0.1651        |
| W5       | (2;3:4) | (4;5:6) | (2;3:4) | (1/2:1:2) | (1/1:1) | (2;3:4) | (4;5:6) | (4;5:6) | (2;3:4) | 0.2667        |
| W6       | (1/2:1:2) | (1/2:1:2) | (1/4;1:3:1/2) | (1/4;1:3:1/2) | (1/1:1) | (1/2:1:2) | (1/4;1:3;1/2) | (1/6;1:5:1/4) | 0.0555        |
| W7       | (2;3:4) | (1/4;1:3;1/2) | (1/2:1:2) | (1/4:1:3;1/2) | (1/6:1:5:1/4) | (1/2:1:2) | (1/1:1) | (1/2:1:2) | (1/6;1:5:1/4) | 0.0592        |
| W8       | (1/2:1:2) | (1/2:1:2) | (1/2:1:2) | (1/6:1:5:1/4) | (2;3:4) | (1/2:1:2) | (1/1:1) | (1/2:1:2) | 0.0904        |
| W9       | (1/2:1:2) | (2;3:4) | (2;3:4) | (1/2:1:2) | (1/4:1:3:1/2) | (4;5:6) | (4;5:6) | (1/2:1:2) | (1/1:1) | 0.1546        |

Note: CR = 0.0839, W stands for weakness.
1) POLICY UNCERTAINTY
In recent years, countries have been promoting new models for infrastructure investment and financing and for developing the application of blockchain in the financial field. However, with regard to the supervision of blockchain technology, all interested countries are in an exploratory period, and each has its own policies. Although there is unanimous agreement that blockchain has great potential, the application of the technology in the infrastructure industry remains limited, largely because infrastructure projects have a profound impact on many areas.

2) ABSENCE OF LEGAL SUPPORT
As blockchain technology is in its infancy, there may in practice be conflicts with existing laws and regulations [11], [13], [14]. For instance, the ownership of virtual property is not clearly defined in law, and it is temporarily unclear how people conduct digital currency transactions in the financial field. Therefore, at this stage in China, the tokenization of infrastructure assets involves significant legal risks. In addition, infrastructure investment and financing involves many contracts, including project contracts, loan contracts, and insurance contracts. When smart contracts that can automatically execute transactions are adopted, current contract law, which imposes responsibilities and obligations on all parties to a transaction, is no longer applicable [50]. In other words, the effectiveness of smart contract execution is open to question. In engineering projects, amendments to contracts and agreements are common during project implementation; because smart contracts need to be written in code in advance, there is a lack of flexibility in handling changes. The investment and financing of infrastructure projects involves multiple participants representing many nodes in the corresponding blockchain system, and configurations, languages, and networks vary with the processing capabilities of each node. In general, the alliance chain is a network between different regions, or even different countries, and it therefore involves many nodes and a range of local laws.

3) TECHNICAL CHALLENGES
From a technical perspective, the blockchain has a number of flaws. Every blockchain account has a unique set of public and private keys, and the user needs their private key to access the fund account. If the user loses the key, they lose control of the funds. In addition, when the conditions match the contractual stipulations, the smart contract automatically executes the instruction. However, if the algorithm gives the wrong instruction, the manager may not detect the error, and this can have serious consequences [37]. Furthermore, although blockchain transmits information, it does not guarantee the quality of that information [51]. Similarly, because the nodes are connected through the network, the transactions on the blockchain are affected by the condition of the network, with network delays threatening the success of a transaction. These shortcomings can cause tremendous losses to infrastructure projects, and if project funds are not in place, the project will be interrupted. There is also concern about the adverse environmental impact of the energy consumed during blockchain operation.

C. OPPORTUNITIES
In the opportunities group, O6 (successful applications in other industries) was ranked first, followed by O4 (optimization of social norms and organization forms), O3 (increased investor confidence), O2 (new infrastructure initiative opportunities), and O1 (national policy support in blockchain). The lowest weighting was that of O5 (stock market expansion). These results show that blockchain, as an infrastructure in which it is important to take full advantage of other emerging technologies, affords great opportunities, because the state promotes intelligent construction. In addition, innovation in the securities market is conducive to the development of blockchain-based financing.

| Opportunity | O1 | O2 | O3 | O4 | O5 | O6 | Local Weight |
|-------------|----|----|----|----|----|----|-------------|
| O1          | (1,1;1) | (1/2;1) | (1/4;1/3;1) | (1/6;1/5;1) | (2;3) | (1/6;1/5;1) | 0.0736 |
| O2          | (1/2;1) | (1;1) | (1/4;1/3;1) | (1/4;1/3;1) | (2;3) | (1/6;1/5;1) | 0.0802 |
| O3          | (2;3) | (2;3) | (1;1) | (1/2;1) | (4;5) | (1/4;1/3;1) | 0.1977 |
| O4          | (4;5) | (2;3) | (1/2;1) | (1;1) | (6;7) | (1/2;1) | 0.2735 |
| O5          | (1/4;1/3;1) | (1/4;1/3;1) | (1/6;1/5;1) | (1/8;1/7;1) | (1;1) | (1/6;1/5;1) | 0.0369 |
| O6          | (4;5) | (4;5) | (2;3) | (1/2;1) | (4;5) | (1;1) | 0.3381 |

Note: CR = 0.0359, O stands for opportunity.

1) NATIONAL POLICY SUPPORT
Blockchain technology has become part of national science and technology strategy. Since the Ministry of Industry and Information Technology issued its White Paper on China’s Blockchain Technology and Application Development (2016) and the State Information Office its Regulations on the Management of Blockchain Information Services, China has placed great emphasis on the development of blockchain technology. As of 2018, nine provinces (cities) across the country had launched blockchain industry funds, to a total of nearly $6 billion. Blockchain is one of the critical areas in the New Infrastructure...
strategic plan, an important field for the implementation of “blockchain plus,” as blockchain will be integrated with emerging technologies such as 5G, the Internet of Things, and artificial intelligence [52], and the Chinese government encourages exploration of blockchain technology to stimulate the economy. In 2019, 328 blockchain application projects were implemented, including 96 financial projects (finance being the most popular field). Supportive domestic policies and an environment conducive to the active development of new technologies have brought opportunities for the application of blockchain in infrastructure investment and financing.

2) SECURITIES MARKET INNOVATION

The application of blockchain brings innovation to the securities market. Banks and other financial institutions, as well as Internet giants, have already applied blockchain in securities transactions. For example, the NASDAQ exchange and the blockchain startup company Chain.com have launched the Linq platform for private equity transactions. The World Bank cooperated with the Commonwealth Bank of Australia to issue a “bond-i” financial product based on blockchain technology, using distributed ledger technology to record its transactions in the secondary market. The Bank of Communications offers a blockchain asset securitization platform for the full lifecycle business functions of ABS products from issuance. JD Digital Technology has developed its ABS Standardization blockchain solution, and Guangfa Securities has launched an independent research and development ABS cloud platform based on blockchain.

Infrastructure asset securitization, infrastructure equity funds, and other products have enormous potential. The introduction of blockchain technology is seen as a solution to the current problems, because the need to diversify asset risks is in line with the characteristics of blockchain decentralization [53]. For investors, infrastructure projects with transparent and accessible information guarantee the credibility of assets, enhance confidence, and increase the recognition of the infrastructure industry as an investment opportunity. In other words, blockchain technology enhances investor confidence, and this is conducive to addressing the lack of funds for infrastructure projects.

3) POSITIVE INFLUENCE OF “BLOCKCHAIN PLUS”

With the country as a whole relying on big data and cloud computing, blockchain technology is conducive to breaking boundaries between the government, financial institutions, state-owned enterprises, and private enterprises to build a common asset database for knowledge-sharing. The peer-to-peer distributed structure built by blockchain eliminates the coercive factors that affect fairness, making the government and contractor nodes equal within the system. The new “trust” method may also give contractors more freedom. When the application of smart contracts matures, the remaining distinctions between different parties in financing contracts will disappear. Thus, the impact of the application of blockchain lies not only in the technological progress it brings but also in changes to the operating rules and organizational forms of the industry [54].

D. THREATS

In the threats group, T3 (risk of money laundering, tax evasion, and hacking) was ranked as the most important factor, followed by T4 (ICO ban) and T6 (conflict with the traditional industry interest chain). The least important factors in this group were T2 (shortage of technical talent) and T8 (lack of interest to traditional corporates). It follows that relevant regulations and laws should be established to protect stakeholders’ rights and prevent negative impacts. A comprehensive training system should be established to educate more technicians and management personnel to counter the threats posed by technical obstacles and competitors.

TABLE VII

| Threat | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | Local Weight |
|--------|----|----|----|----|----|----|----|----|--------------|
| T1     | 1:1:1 | (2;3;4) | (1/4:1/3:1/2) | (1/4:1/3:1/2) | (1/2:1/2) | (1/2:1/2) | (1/4:1/3:1/2) | (1/2:1/2) | 0.0777 |
| T2     | (4/1:3/1:2) | (1:1:1) | (1/8:1/7:1/6) | (1/8:1/7:1/6) | (1/6:1/5:1/4) | (1/6:1/5:1/4) | (1/6:1/5:1/4) | (1/2:1/2) | 0.0300 |
| T3     | (2:3:4) | (6:7:8) | (1:1:1) | (1/2:1/2) | (4:5:6) | (1/2:1/2) | (2:3:4) | (4:5:6) | 0.2568 |
| T4     | (2:3:4) | (6:7:8) | (1/2:1/2) | (1:1:1) | (1/2:1/2) | (1/2:1/2) | (2:3:4) | (4:5:6) | 0.1830 |
| T5     | (1/2:1/2) | (4:5:6) | (1/6:1/5:1/4) | (1/2:1/2) | (1:1:1) | (1/4:1/3:1/2) | (2:3:4) | (2:3:4) | 0.1174 |
| T6     | (1/2:1/2) | (4:5:6) | (1/2:1/2) | (1/2:1/2) | (2:3:4) | (1:1:1) | (1/1:1) | (2:3:4) | 0.1647 |
| T7     | (2:3:4) | (4:5:6) | (1/4:1/3:1/2) | (1/2:1/2) | (1/1:1) | (1/2:1/2) | (2:3:4) | (2:3:4) | 0.1251 |
| T8     | (1/2:1/2) | (1/2:1/2) | (1/6:1/5:1/4) | (1/6:1/5:1/4) | (1/4:1/3:1/2) | (1/4:1/3:1/2) | (1/4:1/3:1/2) | (1:1:1) | 0.0453 |

Note: CR = 0.0755, T stands for threat.

1) INCOMPLETE LEGISLATION

From the perspective of laws and policies, the legal system and industry norms related to blockchain technology are incomplete, which is an obstacle to effective legal supervision [11], [13], [14]. There are no unified industry standards anywhere in the world. In China, although the Blockchain Information Service Management Regulations, Blockchain Privacy Protection Regulations, and other blockchain management documents have been issued, there are stark regional differences in policy. This lack of unified technical standards and industry norms poses significant risks; the lack of legal and regulatory systems means that there is insufficient legal protection for the application of blockchain to infrastructure investment and financing.

China prohibits the issuing of digital currency, and the regulatory authorities are cautious in this area [52], [55]. The
progress of asset tokenization is slow, because criminals can use the anonymity of the technology to carry out money laundering, financing of terrorism, tax evasion, or hacking, without fear of being traced. When such activities occur, the losses for infrastructure investment and financing, which usually involve large transactions, are substantial [51].

2) COMPETITOR-REITs
In addition to blockchain, other investment tools are supported by new national policies. In 2020, the China Securities Regulatory Commission and the National Development and Reform Commission jointly issued their Notice on Promoting the Pilot Work of Real Estate Investment Trust Funds (REITs) in the Infrastructure Sector, marking the official launch of the much-anticipated pilot of publicly funded REITs in the domestic infrastructure sector. Although REITs are relatively new in China, they have been used in developed countries for many years and are established as a long-term investment tool with a high proportion of dividends and a high risk-to-return ratio. They are seen as high-quality, mature financial products. They also have a low investment threshold and strong liquidity, are anti-inflationary, and are supported by national policies. Nevertheless, compared with ICOs, REITs have a long way to go.

3) TECHNICAL OBSTACLES
In the traditional infrastructure industry, it is difficult to promote the application of blockchain technology. On the one hand, the application of new technologies requires a lot of research, at a time when the industry is facing a huge shortage of professional talent, especially people with a mastery of the core technologies [56], [57]. According to the Research Report on Talent Supply and Demand in China’s Blockchain Industry in 2019, 42% of job vacancies in the five major cities of Beijing, Shanghai, Guangzhou, Shenzhen, and Hangzhou are concentrated in the field of technology development, 15% in the field of product and operation, and only 2% in sales. The development and commercialization of blockchain is still at a preliminary stage, and people find it difficult to understand and apply blockchain technology as a whole. Construction professionals and companies sometimes cannot grasp the relevant processes of applying blockchain, where it should be implemented, and how to obtain approval to do so.

Similarly, established companies are not necessarily willing to employ blockchain, as the industrial and interest chains of the infrastructure industry are already in place, and the emergence of new technologies represents a threat to those existing chains in the current investment and financing process [41]. Compared with startups, traditional companies are also less inclined to apply new technologies and participate in project information-sharing. These factors complicate the wider application of blockchain technology in infrastructure investment and financing.

VI. FRAMEWORK FOR A BLOCKCHAIN-BASED INFRASTRUCTURE FINANCING SYSTEM
In line with the concept of blockchain and the process of infrastructure investment and financing, and taking the issuing of project revenue bonds as an example, this study proposes a conceptual model for infrastructure investment and financing management blockchain (see Fig. 2), which is then realized in Hyperledger Fabric.

The alliance chain nodes are categorized according to the participants in the financing structure, including the government agency node, SPV node, intermediary node, brokerage node, bank node, and investor node (see Fig. 2). For example, the government agency node consists of the Ministry of Finance, industry authorities, municipal and provincial development and reform commissions, and regulatory agencies, whereas the intermediary agency node consists of law firms, accounting firms, and credit rating agencies. After verification, each node enters the alliance chain and obtains a unique set of public and private keys. The public key is disclosed, and all information that occurs on each node is encrypted and uploaded with the private key. For example, when an enterprise participates in infrastructure project investment and financing, it must register an account in the blockchain-based infrastructure financing system using a social credit code. The system verifies the business type, qualification level, scale, and other information to determine whether the company meets the requirements. After verification, the system assigns the company its public and private keys, discloses the public key information, and uploads project-related documents and transaction data; the company can then access data files uploaded by other nodes.

The blockchain database for issuing project revenue bonds involves a six-stage process (see Fig. 3): from the project initiation in the preparation phase, through to the signing of the contract, the determination of the financing structure, the intermediary agency rating and analysis of the fundraising, to the issuance plan. Bonds are issued after the design has been approved by the Development and Reform Commissions, investor registration enables bond information to be obtained, and finally the bank monitors the cash flow of debt repayment and financial subsidies in real time throughout the life cycle of the infrastructure project. Blockchain technology runs through all the processes, including the establishment of the project, the stages before and after bond issuance, investor registration, and difference compensation. Early participants can continue to track the progress of the financing, and those who join later can track the historical data to understand the progress of the project.
FIGURE 2. Conceptual framework for the blockchain-based infrastructure financing system.

FIGURE 3. Data flow in the blockchain-based infrastructure financing system.
Once the project has been initiated, the platform can collect and record data and documents for every transaction between the participants in the alliance chain. Each node in the chain stores the information that relates to that node and the project in the appropriate sequence. The government node provides documents such as the financial affordability demonstration report, the project implementation plan, the project contract, the companies’ cooperation agreement, and the bond issuance plan review. After the SPV has been established, the SPV nodes provide contract documents and smart contract codes, including loan contracts, guarantee contracts, financing contracts, targeted issuance agreements, and difference compensation agreements. The intermediary node provides the financial evaluation report, legal opinion, rating results, and other documents that relate to the project income and financing fund balance plan. The host brokerage node provides the project income bond issuance plan and investor information, among other documents.

If the bond issuance is successful, the smart contract automatically allocates funds from the special account to securities firms, credit rating agencies, law firms, accounting firms, and other institutions to complete the financing. For the duration of the bond, the bank node monitors and updates in real time the cashflow of the special account for the funds raised, the special account for project collection, and the bond repayment account. The smart contract also automatically repays the principal and interest to the investors. If the debt repayment funds are sufficient, the smart contract automatically activates the difference compensation mechanism and allocates funds from the difference compensation pool account.

VII. CASE STUDY
This study validated the proposed framework using IBM’s Hyperledger Fabric platform version 2.1.1, deploying peer nodes to represent the government’s administrative institutions, the SPV institution, the financial intermediary institution (including law firms and accountants), the broker selling the private bond, and the investors and banks. It also deployed one orderer node to coordinate the activities between peer nodes.

This study developed chaincodes (AKA smart contract) and deployed the chaincode logic to the peer and orderer nodes using Hyperledger Fabric’s own deployment technology to simulate six types of transactions during the construction financing process on the blockchain. The initial experimental results substantiate the feasibility of using blockchain technology as a securable transaction management platform for infrastructure financing.

To secure the information transferred between nodes, the platform also established three channels for private data sharing between the government agency, the financial institution, and the intermediary institution. The architecture of our blockchain platform is shown in Fig. 4.

For the purposes of the experiment, each organization defines only one peer node, and the components of the blockchain network contains four peer nodes: one orderer node and three secure interorganizational channels defined as follows:

- **Government node:** This node is responsible for creating and uploading construction contracts, including the contract, project feasibility analysis report, and bidding documents. It initiates the bond creation process and uploads the bond configuration document onto the ledger.
- **Financial institution node:** This node provides the project information and construction bonds, such as the contract agreement and associated legal documents, the buyer and seller regulations, the guarantee agreement, and the leasing agreement. It constructs all necessary components of a bond product.
- **Intermediary node:** This node contains third-party professionals providing legal and accounting services and is responsible for reviewing the bond detail information and providing legal support and bond ratings.
- **Investor node:** This node appraises the bond information and then takes appropriate actions, including buying, selling, and transferring.
- **Orderer node:** This node is required to establish the Hyperledger Fabric system. It uses the Raft algorithm to order the messages from each peer node, ensuring that each message is handled appropriately by the network without exception; even if the network crashes, it guarantees that the information can be recovered.
- **Three secure channels:** The channels are used to secure information flows in interorganizational communications. Three secure channels transfer data between government and financial institutions, government and intermediary parties, and financial institutions and intermediary parties.

The business logics of each of the participating nodes are written in the Go programming language and deployed as a chaincode package onto each node container hosting the node. The functionality and APIs of each node are defined in Table VIII. The blockchain network is hosted on a docker for the Windows 10 desktop environment version 20.10.6, with...
container image OS: ubuntu 20.04. Table IX gives the docker container configuration for the peer nodes and ordered nodes in the network.

| Node Type          | Functionality                                      | APIs                |
|--------------------|----------------------------------------------------|---------------------|
| Government         | • Create policy and agreement resources            | CreateResource()    |
|                    | • Make and request approvals                       | Approval()          |
|                    | • Track bond life cycles                           | Deny()              |
| Financial Institutions | • Create report resources                         | CreateResource()    |
|                    | • Submit bond documents                            | SellBond()          |
|                    | • Perform bond sale operations                     | TransferBond()      |
| Intermediary       | • Create rating documents                          | CreateResource()    |
|                    | • Provide legal documents                          |                     |
|                    | • Provide accountant documents                     |                     |
| Investor           | • Create investor information                      | CreateResource()    |
|                    | • Perform bond buying operations                   | BuyBond()           |

In the configuration, we set the orderer node to initialize the network and create the genesis block. The orderer node is also responsible for generating the keys used during network startup. We used port 7050 to listen to messages for the orderer node, and we used Hyperledger’s default certificate and authorization to generate public and private keys for information signing purposes.

When generating the keys to encrypt data stored in the blockchain, the default Hyperledger key generation mechanism was applied. For the port configurations, we chose ports 7051 (Government), 9051 (Financing), 10051 (Intermediary), and 10151 (Investor) to send and perform http requests to and from the ledger to update the resources stored on the blockchain. We chose port 7052 (Government), 9052 (Financing), 10052 (Intermediary), and 10152 (Investor) to receive http requests from each node’s chaincode package.

Figure 5 shows the bond creation, issuance, and ownership transfer process.

Step 1: The government node initiates a financing operation by calling CreateResource to specify the resource type. This type of resource involves project agreement and project disclosure. The text-based information is transferred into JSON (JavaScript Object Notation) format and stored on blocks. Then, when the orderer node receives the message from the government node, it validates the authenticity of the message using asymmetric encryption techniques.

Step 2: Through secured channels, the government node informs the financial institutions of the creation of the initial financing resources of a construction project. No other nodes can obtain the secure message passed via these secure channels; at this stage, only the government node and the financial institution node are aware of the creation of a financing need for a construction project.

Step 3: After being securely notified, the financial node retrieves the information from the ledger related to construction projects that need financing. It then starts to design the bond and calls CreateResource to upload the bond documents onto the chain. If it is necessary to change the resource property, the owner of the resource can do so by calling on ChangeResourceProperty.

Step 4: The financial institution node sends bond information securely to the designated intermediary parties deemed eligible to participate in the financing process.

Step 5: The intermediary parties are authenticated, allowing them to read the ledger data and access the bond information. They then carry out the appropriate professional services, such as evaluating risk, providing ratings, and legal consultancy activities, storing all relevant information on the chain.

Step 6: The intermediary parties notify the financial institution that their services have been completed.

Step 7: The financial institution collects all the required documents and verifies each milestone during the bond creation process. The financial institution sends a message to the government node indicating readiness for bond issuance.

Step 8: The government reviews and approves the design of the bond and notifies the financial institution of its decision.

Step 9: The financial institution creates a bond resource and marks the bond as sellable on the chain; it also sets its owner to be the government.

Step 10: The financial institution broadcasts the bond issuance via secure channels to all investor nodes on the network (in this case, we created only one investor node for the purposes of demonstration).

Step 11: The investor evaluates the bond information, including time, project, rate, and price. If it wants to buy the bond, it submits a purchase request, which is transferred into a blockchain transaction and handled by the ordered node. The ordered nodes validate the request and call on the financial institution node to process it. The financial node accepts the request and performs the pre-check to verify the ownership of the target bond, the amount and price of the bond, the transaction date and time, and the eligibility of the buyer. After verification, the financial node issues the sell command by calling the SendBond API. The sell bond API internally calls transfer resource API, which interacts directly with the blockchain to transfer the ownership of the bond to the
This experiment was performed using a single box with Intel Core (TM) i7-10510 CPU @ 1.80 GHZ with usable memory of 15.7 GB. It proves that the blockchain-based network can serve as a financing platform for infrastructure project financing with secure features and a high degree of transparency.

From a resource management perspective, the documents are managed by blockchain, which prevents tampering and makes it easy to track changes. Each transaction, including bond selling and buying, is made more reliable by blockchain’s distributed consensus algorithm and asymmetric encryption techniques.

| Table IX: Configuration of Each Node in the Network |
|------------------------------------------------------|
| **Node Name** | **Node Type** | **Chaincode Package** | **Listening Port** | **Http/Https** | **Key Management Scheme** |
|---------------|---------------|-----------------------|--------------------|----------------|--------------------------|
| Orderer       | Ordered node  | N/A                   | 7050               | Http/Https     | Server generated key using ca.crt |
| Government    | Peer node     | Deployed Government chaincode package | 7051 for node | Http/Https | Government node-owned certificate to sign and validate keys |
| Financial     | Peer node     | Deployed Financial chaincode package | 9051 for node | Http/Https | Financial node-owned certificate to sign and validate keys |
| Intermediary  | Peer node     | Deployed Intermediary chaincode package | 10051 for node | Http/Https | Intermediary node-owned certificate to sign and validate keys |
| Investor      | Peer node     | Deployed Investor chaincode package | 10151 for node | Https       | Investor node-owned certificate to sign and validate keys |

**FIGURE 5.** Data flow during bond creation, issuance, and ownership transfer.

**VIII. CONCLUSION**

China is in a stage of rapid urbanization, and the scale of its cities is expanding at pace, with a corresponding increase in the need for infrastructure and huge demand for investment funds [58]. However, given the incompleteness of laws and policies and the characteristics of infrastructure projects, government credit, and other factors, it is difficult for private capital to finance infrastructure projects. The government therefore seeks to address the constraints of insufficient infrastructure investment funds and high financial pressure and to moderate their effects on the pace of infrastructure project construction. This study analyzes the financing instruments that have been deployed in China, most of which are characterized by complex procedures, insufficient transparency and openness in relation to assets, and lack of project data. The study aims to show how to meet the huge investment capital need for infrastructure, ease the financial pressure on the government, and broaden financing venues by proposing a framework for a blockchain-based infrastructure financing system.

Blockchain technology is being developed vigorously as part of China’s New Infrastructure strategic plan, but there has been little research on infrastructure investment and financing based on blockchain. This study addresses this gap with a fuzzy AHP-SWOT analysis of the application of blockchain technology to infrastructure investment and financing from the political, economic, social, and technical aspects.
The fuzzy AHP-SWOT analysis discovered the internal strength and weaknesses as well as the external opportunities and threats in using blockchain-based financed system on infrastructure projects in China and ranked each aspect by calculated weight through expert opinions. For instance, blockchain-based infrastructure investment and financing management has three principal advantages over traditional financing instruments. The first advantage concerns information penetration. Most current financing markets have been criticized for opaque asset information, which causes information asymmetry. The traceable and anti-tampering characteristics of blockchain technology make financing visible, facilitate credit transfer, and help investors to manage risk. In addition, asset information penetration promotes and simplifies transparent supervision. The second advantage relates to improvements in efficiency. The traditional financing process is lengthy and complex. In contrast, distributed ledger technology facilitates an information consensus among the project participants, simplifies the financing process through smart contracts, and improves the efficiency of the collaborative work of all parties. The third advantage is a reduction in costs. Because banks and securities markets charge high intermediary fees, the use of smart contracts to allocate funds automatically, together with real-time monitoring of the flow of project funds, can significantly reduce time and operating costs.

Based on the findings of the fuzzy AHP-SWOT analysis, a framework for blockchain-based infrastructure finance system is designed to make the best use of the strength and advantages, meanwhile, to offset the weaknesses and evade threats. The framework design focused on the participants as nodes in the blockchain system and their relationships, which in accordance with the infrastructure finance practice in China. The transactions flow is in line with both the blockchain technology mechanism and infrastructure finance procedure. This study validated the proposed framework using IBM’s Hyperledger Fabric platform version 2.1.1, deploying peer nodes to represent the government’s administrative institutions, the SPV institution, the financial intermediary institution (including law firms and accountants), the broker selling the private bond, and the investors and banks. It also deployed one orderer node to coordinate the activities between peer nodes.

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