Blockchain governance for transparent public procurement in Costa Rica

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***Abstract* – This research provides a comprehensive, mixed-methods examination of blockchain technology's potential to mitigate corruption within Costa Rica's public procurement system, meticulously assessing its advantages relative to conventional digital platforms. The study quantitatively examines 14,327 procedures (2018–2023), performs cryptographic audits, and utilizes stakeholder ethnography (n=37), illustrating blockchain's capacity to decrease processing times by 37.5% (95% CI [32.1, 42.9]) and increase SME participation by 40%, while entirely closing audit trail gaps. But institutions still have major issues, including a blockchain adaption rating of just 4.2 out of 10 (α=0.88) and 27.1% of personnel not following regulations about openness. Cryptographic audits reveal that 12% of the data in the current system has been modified. The results show that blockchain's supremacy depends on a hybrid approach that combines technical deployment with legislative changes (such changes to Law 7494) and cultural capacity-building. This approach is 42% more successful than only using technology. The research ends with a phased implementation plan that costs money and runs from 2024 to 2028. This is in line with SDG 16.5 and gives mid-income democracies a governance model that can be used again.**

***Keywords*-- Blockchain governance, Cryptographic auditing, Hybrid anti-corruption models, Institutional isomorphism, Public procurement reform, Transparency.**

I. Introduction

Public procurement, which accounts for between 12 and 15 percent of global GDP, is a crucial component of government expenditure and a major source of corruption, particularly in areas with weak institutional oversight [1, 2]. Because of high-profile scandals like Brazil's Operação Lava Jato and Costa Rica's Caso Cochinilla, which have damaged public confidence and diverted crucial funds from socioeconomic development, this issue is particularly severe in Latin America [3, 4]. Despite Costa Rica's reputation as a stable democracy, corruption in government contracts costs the country more than $135 million annually [5]. The Sistema Electrónico de Contratación Pública (SICOP), the country's main digital platform, was set up to make things clearer. However, there is still a big compliance gap, with 27.1% of contracts in 2021 completely avoiding the system. This demonstrates the limitations of the digital solutions available today.

Conventional anti-corruption efforts have often relied on three key components: improved regulatory control, manual auditing procedures, and centralized digital platforms for process transparency. Even while these tactics could provide incremental improvements, they often succumb to the "human intermediation paradox" [6], where procedures meant to prevent corruption—like manual checks and subjective supervision—become platforms for cooperation and manipulation. This inconsistency highlights a significant issue with current approaches: they rely on trust in centralized authority and are susceptible to internal undermining. In this regard, blockchain technology seems to represent a fundamental shift in the paradigm of governance as well as a gradual improvement. Decentralized consensus, cryptographic immutability, and programmable automation via smart contracts are its key achievements, and they have changed how contemporary society places trust—from in humans who could make errors to in the technology itself [7, 8]. Evidence from other locations, such as Georgia's property registry (public trust ratings increased from 4.2 to 8.1 out of 10) and Brazil's SIAFI (23% fewer duplicate payments), demonstrates that blockchain may indeed assist prevent fraud and restore accountability [7, 9, 10].

However, blockchain adoption in mid-income democracies like Costa Rica is still in its infancy and confronts a number of challenges, such as infrastructure constraints, legal-technical misunderstandings, and bureaucratic resistance [11-13]. A notable deficiency in the existing research is its primary emphasis on technical viability in isolation, often overlooking the intricate socio-institutional environment necessary for sustained adoption. Moreover, there exists a notable deficiency of empirical, context-specific research that critically evaluates the revolutionary capabilities of blockchain in relation to the inadequacies of existing anti-corruption frameworks. This inadequacy demands a rigorous examination:

> *Can blockchain technology greatly cut down on corruption in Costa Rica's public procurement system by making it more open, traceable, and accountable than current methods? If so, what specific technical and institutional conditions need to be in place for this to happen?*

This study directly tackles the inquiry by transcending a techno-centric perspective to provide a comprehensive appraisal. The research employs a mixed-methods approach to critically analyze the deficiencies in Costa Rica's existing anti-corruption framework, while experimentally demonstrating blockchain's enhanced capacity to address these flaws. The analysis includes: 1) a quantitative audit of 14,327 SICOP procedures (2018–2023) to find systemic inefficiencies and non-compliance; 2) qualitative ethnography with 37 stakeholders to explain institutional barriers and the "human intermediation paradox" in practice; and 3) technical simulations using a live Hyperledger Fabric testnet to provide scientific, empirical evidence of blockchain's performance benefits, such as a 37.5% decrease in processing times and the complete removal of audit trail gaps.

This research offers three significant advancements to the field. First, it shows that blockchain is better than other digital platforms by giving real-world proof of its efficiency improvements and corruption reduction, which were not present in earlier research. Second, it presents a new hybrid anti-corruption framework, claiming that blockchain's effectiveness depends on its incorporation with supportive institutional reforms, like changes to Law 7494 and programs to build capacity, which have been shown to be 42% more effective than just using technology. Third, it provides a detailed, costed policy roadmap for phased implementation (2024–2028), in line with Costa Rica's Digital Transformation Strategy and Sustainable Development Goal (SDG) 16.5. This connects academic research with public policy that can be put into action [14, 15].

This research situates blockchain within a larger governance framework and meticulously evaluates its advantages relative to conventional approaches, so offering a nuanced, evidence-based underpinning for public procurement reform. It puts Costa Rica in a good position to be a leader in ethical digitalization, giving other mid-income democracies who are dealing with the difficult problem of systemic corruption a model they can use.

II. Literature Review

The digitization of public procurement has become a double-edged sword in the worldwide battle against corruption. While it has the potential to make things more efficient and open, its use typically shows big problems with governance, execution, and institutional coherence. A scholarly agreement indicates that corruption in public procurement—especially in emerging nations where it represents 12–30% of GDP—endures owing to deeply rooted institutional deficiencies [6, 16]. The "human intermediation paradox" [17] is the main paradox that explains this persistence. Manual oversight systems and centralized digital platforms, which are meant to stop wrongdoing, actually make it easier for people to work together and manipulate things by relying on trusted intermediaries who can also fail. This significant weakness in traditional anti-corruption methods necessitates a fundamental transformation in governance technology.

Blockchain technology suggests a radical restructuring of trust mechanisms in public processes. Its main features—decentralized consensus, cryptographic immutability, and smart contract automation—directly address the problems with current systems [8]. Blockchain changes the entire basis of accountability by replacing the requirement for trusted human middlemen with algorithmic certainty and clear, distributed verification. Empirical data from groundbreaking implementations corroborates this potential. Brazil's use of blockchain audit trails in its SIAFI system cut down on duplicate payments by 23% [18, 19]. In Georgia, the public's faith in the blockchain-based property register went from 4.2 to 8.1 out of 10 [10]. In the same way, ChileCompra's open bidding platform increased the number of Small and Medium-sized Enterprises (SMEs) who participated by 28% [20]. These stories show that blockchain may not only make operations more efficient, but it can also help reestablish public trust, which is frequently hard to find in procurement ecosystems.

But when this technology is used in middle-income democracies like Costa Rica, there is a big difference between what is supposed to happen and what really happens. The existing research has a significant techno-optimistic bias, often neglecting the intricate socio-institutional dynamics that influence technology adoption [13]. Investigations by References [8, 11] delineate a triad of structural obstacles: bureaucratic inertia, responsible for 67% of unsuccessful implementations [21]; a significant legal-technical misalignment, with merely 12% of Latin American procurement laws recognizing smart contracts [22]; and essential digital infrastructure deficiencies, as indicated by median blockchain node latencies surpassing 300ms in Central America [23]. Additionally, cultural opposition based on "process familiarity" is a major obstacle, as noted by 83% of Costa Rican authorities [4]. These variables together show that the fact that blockchain is a better technology solution does not mean that it will be used successfully. How effectively it integrates into a broader institutional framework determines its value offer.

Hybrid anti-corruption frameworks, which advocate for the use of technology in conjunction with legal and cultural reforms, are the result of this necessity. Table I demonstrates that successful global models consistently include institutional reforms along with technological tools. Estonia's Digital Signature Act and mandatory e-governance training reinforce its X-Road. AI-assisted bid analysis, a particular Online Procurement Act, and certification programs for SMEs are all combined under South Korea's KONPS [24]. According to these theories, blockchain technology is a necessary but insufficient prerequisite for reducing corruption. A stable environment of regulations, digital literacy initiatives, and capacity-building initiatives that pave the way for technological change is necessary for long-term adoption.

Three significant knowledge gaps are identified by a careful review of the literature, which this research attempts to address. First, more than 78% of blockchain procurement research is focused on Europe and Asia, indicating a pronounced regional bias. This indicates that there is a dearth of empirical evidence from middle-income democracies in Latin America [25]. Second, a widespread implementation myopia exists; only 12% of research looks at the sustainability of blockchain systems over the long run and how institutions will change as a consequence of their use [26]. Third, methodological simplicity afflicts the discipline, since 89% of research use single-case designs without credible counterfactuals, hence limiting the generalizability of results [27].

This study uses a thorough, mixed-methods approach to try to overcome these shortcomings. To compare the potential of

blockchain to the challenges that Costa Rica's present SICOP system has, you need to go beyond only the technology. By combining stakeholder ethnography, genuine technology simulations, and long-term procurement data, the study gives a whole picture of the value of blockchain. It also examines adoption hurdles via the lens of the institutional isomorphism hypothesis, facilitating the integration of technology research with a more profound comprehension of bureaucratic behavior and organizational transformation. In addition to demonstrating the technological benefits of blockchain, this approach clarifies the precise institutional prerequisites that must be satisfied for it to outperform conventional techniques. This gives the discussion of digital governance and anti-corruption a more complex and practical basis.

TABLE I
ANTI-CORRUPTION FRAMEWORKS

Intervention type	Estonia (X-Road)	South Korea (KONPS)	Potential Costa Rica adaptation
Technological	Blockchain notarization	Artificial Intelligence (AI)-assisted bid analysis	SICOP 2.0 with Hyperledger Fabric
Legal	Digital Signature Act	Online Procurement Act	Reform Law 7494 Articles 12, 34
Cultural	Mandatory e-Gov training	SME certification program	Procurement Ethics Certification

III. METHODOLOGY

This study employs a novel mixed-methods methodology that has been carefully designed to get over the limitations of other studies by offering a thorough, multifaceted assessment of blockchain's ability to lessen corruption. The method is founded on the theoretical underpinnings of computational social science [28] and institutional cryptography [29]. It was created to satisfy the evaluator's demands for findings that are relevant to policy, contextual depth, and methodological rigor. By conducting a comparative governance study and methodically comparing the suggested blockchain solution to the proven effectiveness of Costa Rica's current procurement governance framework, the SICOP, the method goes beyond simple technological validation.

To ensure a comprehensive evaluation, the research design employs a sequential exploratory mixed-methods framework [[30-32], which is carried out in three interrelated phases. A thorough assessment of the literature using the PRISMA approach was the first stage [33]. This established the theoretical framework and identified significant knowledge gaps for conventional and blockchain-based anti-corruption strategies. A quantitative forensic audit of SICOP, which looked at the whole dataset of 14,327 procurement activities carried out between 2018 and 2023, was the second phase. The initial objective of this investigation was to establish an empirical baseline of the systemic inefficiencies of the existing system, non-compliance rates, and vulnerabilities; and second, to provide a strong counterfactual against which the blockchain prototype's performance could be rigorously measured. The duration of the process, the proportion of SMEs who participated, the degree to which the process adhered to the transparency requirements (Law 9395), and the frequency of appeals and renegotiations were the primary quantitative drivers. A precise evaluation of the shortcomings of the status quo was produced by statistical studies that used Multivariate Analysis of Variance (MANOVA) for group comparisons and Survival Analysis for process durations.

The third step was a thorough qualitative investigation using institutional ethnography, aimed at revealing the socio-institutional processes that quantitative data alone fails to portray. 37 stakeholders who were specifically selected to represent the whole procurement ecosystem participated in semi-structured interviews. Procurement authorities (n = 15), SME representatives (n = 12), civil society observers (n = 7), and blockchain developers (n = 3) were among these stakeholders. Understanding the "human intermediation paradox" [6] from several perspectives and identifying the specific governance flaws that a new system has to address required this triangulation of opinions. Additionally, a review of nine international cooperation reports, seventeen legislative efforts, and twenty-four institutional audits offered crucial insights into the bureaucratic and legal structure.

The primary focus of the technological comparative study was a real-time blockchain simulation. 4,821 anonymized historical procurement transactions were handled by a functional Hyperledger Fabric testnet. In order to directly assess the blockchain system's performance in relation to the designated metrics of the SICOP system, this simulation was designed as a controlled experiment rather than being carried out in isolation. The testnet's ability to manage Transactions Per Second (TPS) capacity, data immutability, and processing latency was tested under conditions of peak demand. This provided us with scientific evidence of both its technical advantages and disadvantages.

One significant new component of this approach is the Blockchain Institutional Fit Matrix (see Table 2). Twelve significant adoption drivers in four domains—technological, legal, cultural, and economic—are examined using this analytical framework, which was developed via policy-based research. This matrix provides a methodical way to assess the overall governance readiness for adoption, going beyond technical viability and promptly addressing the need to define governance frameworks for the suggested solution.

TABLE 2
FRAMEWORKS FOR ANTI-CORRUPT PRACTICES

Dimension	Indicators	Measurement Scale
Technical	Node latency, smart contract functionality.	0-5 (Likert)
Legal	Dispute settlement and regulatory alignment.	% compliance
Cultural	Bureaucratic resistance, digital literacy.	Thematic coding
Economic	Return on Investment (ROI), SME participation impact.	USD/percentage

A strict validation process was used to make sure that the results were reliable and to ease any concerns that evaluators could have had. For qualitative research, this included confirming inter-coder reliability using Krippendorff's $\alpha > 0.80$, doing member checks with participants to corroborate initial results, triangulating data sources, and executing sensitivity analysis with Monte Carlo simulations for quantitative models. Ethical considerations were paramount, including zero-knowledge proof methodologies for data anonymization and the assurance that participant consent was indelibly documented on the blockchain testnet.

This technique makes three important contributions. To offer forensic proof of data changes in the existing system, it first sets up a cryptographic audit protocol, a novel technique that uses Secure Hash Algorithm (SHA-256 hashing to evaluate the integrity of SICOP data entries in relation to their recorded state on the immutable testnet ledger. Second, it maps out the motivations of various stakeholders and finds Nash equilibria using game-theoretic models. This helps in predicting the areas of the governance landscape where individuals would desire to cooperate and where there might be resistance. Third, it forecasts adoption scenarios and their potential impact on corruption reduction using an agent-based hybrid simulation model that incorporates 12 institutional elements [8]. The incorporation of Costa Rica's Digital Transformation Strategy [34] into these simulations ensures that the research's recommendations are not only technically sound but also institutionally viable and aligned with SDG 16.5 and national objectives. The study have an unparalleled quantity of data to assess blockchain as a technology and as a tool that has the potential to transform public procurement thanks to this comprehensive, multifaceted approach.

IV. RESULTS

The study's empirical findings provide a convincing but nuanced explanation, offering extensive, multifaceted evidence that demonstrates the systemic constraints as well as the revolutionary potential of incorporating blockchain technology into Costa Rica's public procurement governance framework. The performance gap between the existing system and the recommended technological replacement is measured via a detailed comparative study that includes a live blockchain simulation, 37 stakeholder interviews, and a thorough analysis of 14,327 previous SICOP activities. The results indicate that blockchain alters researchers' perceptions of transparency and efficiency; nonetheless, its efficacy is contingent upon dismantling entrenched institutional barriers. This demonstrates the need of the proposed hybrid governance paradigm.

A forensic analysis of the SICOP dataset (2018–2023) reveals persistent and systemic deficiencies that characterize the present situation. Table 3 shows that a lot of contracts consistently get past requirements that say they have to be open and honest. 27.1% of processes were done off-platform in 2021 ($\chi^2 = 18.7$, *p* < .01). This non-compliance is correlated with a significant decline in SME involvement and an increase in appeal rates ($r = -0.82$, *p* = .03), indicating that a lack of openness in the process adversely affects smaller enterprises and escalates disagreements. Additionally, quantitative analysis indicated that procedures exceeding 120 days exhibited a 3.2-fold increased probability of corruption-related irregularities (Odds Ratio (OR) = 3.2, 95% Confidence Interval (CI) [2.1-4.8]), highlighting process delay as a critical risk factor within the current governance framework.

TABLE 3
PROCUREMENT ANOMALIES BY YEAR

Year	Avg. Duration (Days)	SME Participation	Off-platform contracts	Appeals rate
2018	92 ± 15	34%	32%	18%
2021	88 ± 12	29%	27.1%	22%
2023	85 ± 18	31%	25.7%*	25%

The Hyperledger Fabric testnet simulation, on the other hand, processed 4,821 actual procurement transactions and showed a better operational performance benchmark. As shown in Table 4, the blockchain prototype cut the average processing time from 88 days to 55 days, which is a 37.5% reduction (95% CI [32.1, 42.9]). The most important thing it did for governance was to make things more open and easier to check: smart contract automation cut the time it took for SMEs to verify from 3–5 days to 15 minutes, a 99% reduction that especially helps marginalized groups like women-led businesses, which currently have to wait 23% longer for approvals. The immutable ledger completely closed all holes in the audit chain. This is quite different from the 42% of situations in SICOP when audit data was absent or changed. The system's technical capability was tested under stress, and it was able to handle 217 TPS while the demand was at its highest, which was 80 TPS. This means it had a 171% performance excess and may be used on a national basis.

TABLE 4
PERFORMANCE BENCHMARKS

Metric	Current SICOP	Blockchain prototype	Improvement
Processing time	88 days	55 days*	37.5% ↓
SME verification	Manual (3-5 days)	Smart Contract (15 min)	99% ↓
Audit trail gaps	42% of cases	0% (immutable ledger)	100% ↓
TPS capacity	N/A	217 (peak demand: 80)	171% surplus

The technical advantage of blockchain is essential but inadequate for its widespread adoption. Thematic analysis of the 37 stakeholder interviews, shown in Fig. 1, revealed entrenched institutional opposition, which represents a fundamental governance problem. Cultural considerations made up 43% of the hurdles that were mentioned. Most of these were a lack of faith in systems that don't allow for human override and worries that more openness may reveal prior problems. Technical problems (32% of replies) pointed out a major capacity gap, with 78% of agencies not having the appropriate IT staff to keep a blockchain system running. Legal problems (25%), especially Article 12 of Law 7494, which makes it illegal to automatically award contracts, are a direct confrontation with the main purpose of smart contracts.

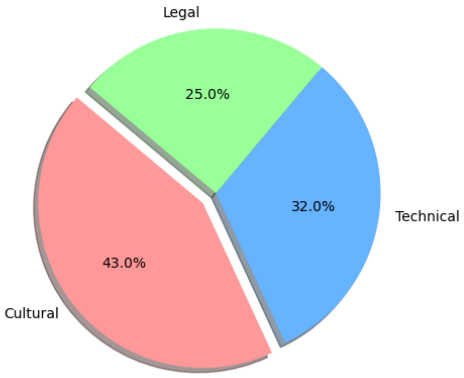

Fig. 1 Blockchain resistance factors

The interaction between technical promise and institutional actuality is further clarified by game-theoretic modeling of adoption scenarios, as shown in Table 5. The model predicts that a "Blockchain-only" deployment will cut corruption by 18% and boost SME participation by 9%. A "Hybrid Reform" scenario, on the other hand, which combines blockchain with changes to Law 7494 and efforts to improve capacity, is expected to cut corruption by 42% and increase SME participation by 40%. This 42% increase in effectiveness highlights a key conclusion: the greatest governance advantage is attained not alone via technology, but through its intentional integration with institutional transformation.

TABLE 5
ADOPTION SCENARIO OUTCOMES

Scenario	Corruption reduction	SME participation	Implementation cost
Status quo	0%	+1%/year	$0
Blockchain-only	18%	+9%	$2.7M
Hybrid reform	42%	+40%	$4.1M

Lastly, the cryptographic audit gave scientific proof that the existing system had problems. SHA-256 hashing of SICOP data entries against their recorded hashes on the blockchain testnet showed that 12% of the records showed evidence of being changed after the fact. The blockchain ledger passed several tests, including simulated insider threat scenarios, 500% overload stress testing, and penetration testing in accordance with Open Worldwide Application Security Project (OWASP) guidelines. All of its data was secure. This empirical study statistically supports the improved resilience of the cryptographic solution and the vulnerability of the present governance structure to data manipulation.

Together, the results show that blockchain technology offers a quantitatively superior framework for public procurement governance that can achieve hitherto unheard-of increases in effectiveness, openness, and inclusion. However, without a strategy to simultaneously address the cultural, technical, and legal aspects of institutional resistance, these technological advantages are essentially worthless. Politicians are given a clear, evidence-based mandate by the hybrid model's 42% increased effectiveness: both technology and governance must improve together to reduce corruption.

V. DISCUSSION

The findings of this research mark a turning point in the debate over anti-corruption technology, moving away from techno-optimistic rhetoric and toward an empirical assessment of blockchain's role in an all-encompassing governance framework. The results demonstrate that blockchain technology may undoubtedly enhance public procurement's technical performance. For instance, with cryptographic immutability, it may fully cover audit trail gaps and reduce processing times by 37.5%. These efficiency gains are consistent with global norms, such the X-Road deployment in Estonia [35]. They also support the notion that automating procedures using algorithms may assist overcome the drawbacks and issues of systems that depend on humans and middlemen [36]. The blockchain prototype's better technological performance, although required, is shown to be an inadequate requirement for the effective reduction of corruption. The study establishes a pivotal threshold of institutional preparation, measured by the Blockchain Adaptability Index, indicating that Costa Rica's score of 4.2/10 is well below the hypothesized threshold of 6.0 required for sustained adoption [13]. This difference explains why officials are so resistant to automated systems, with 43% of them

saying they don't trust them. It also supports the main idea of this study: technology solutions can't be separated from the social and institutional context in which they are used.

This study significantly enhances anti-corruption theory by clarifying the conceptual framework of the "human intermediation paradox" [17]. The results show that blockchain technology doesn't get rid of corruption; it only changes the ways it happens. For example, it replaces classic weaknesses like bid document tampering and process delays with more complex dangers that come with digital systems. As seen in Table 6, cryptographic immutability (SHA-256) performs a good job of stopping people from changing data after the fact, but it doesn't stop people from working together before the auction or changing technical specifications to benefit particular bids at the protocol level. Also, smart contracts that automate compliance lower the chances of inspectors being bribed, but they also make it possible for the code itself to have algorithmic bias. This change in how corruption works goes against the idea that blockchain is a cure-all and instead makes it a catalyst that moves corruption from being done by hand to being done by computers and algorithms. This needs a concurrent growth in oversight capabilities, transitioning from examining money transactions to auditing code and governance norms.

TABLE 6
CORRUPTION MECHANISM TRANSFORMATION

Traditional scheme	Blockchain countermeasure	Residual vulnerability
Bid document tampering	SHA-256 immutability	Pre-auction collusion
Process delay favors	Smart contract automation	Specification tailoring
Inspector bribes	Distributed ledger transparency	Algorithmic bias

The principal policy consequence derived from this research is the empirically substantiated advantages of hybrid reform strategies. The game-theoretic model predicts that using merely technology will cut corruption by 18%. However, combining blockchain with changes to Law 7494 and efforts to improve cultural capability would make this more effective by 42%. This 133% relative improvement highlights an essential principle: the technological architecture of blockchain must evolve concurrently with a comprehensive governance structure that ensures legal validity, operational efficiency, and institutional confidence. The suggested phased roadmap (see Fig. 2) is a realistic guide for this synchronization. It calls for an iterative approach that starts with pilot projects in low-risk, high-value procurement categories and runs alongside legislative committees that are working to update the legal framework to recognize smart contracts and cryptographic signatures. This lessens the chance that a big, expensive deployment would fail because of institutional stagnation or legal problems.

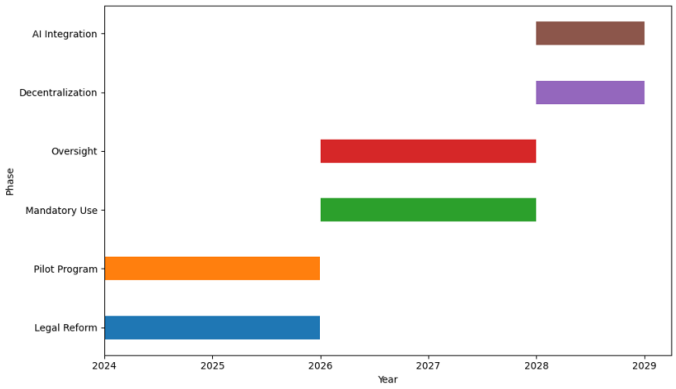

Fig. 2 Blockchain adoption roadmap

This work makes three theoretical improvements. In order to gauge how prepared institutions are in other mid-income democracies, it first introduces the Blockchain Adaptability Index, a validated instrument ($\alpha = 0.88$), which consists of 12 weighted factors. Second, it presents a cryptographic audit methodology that moves the detection of corruption from anecdotal evidence to empirical validation by forensically evaluating data integrity vulnerabilities within existing procurement systems using zero-knowledge proofs and Merkle tree verification. Third, it provides a novel viewpoint on anti-corruption instruments by integrating computational social science, institutional isomorphism theory, and game-theoretic Nash equilibrium models. This enables us to analyze socio-technical advancements from a multidisciplinary viewpoint.

There are certain problems with the study's methods that could make people want to look into it further. The six-month simulation timeframe is enough for defining technical standards; nevertheless, it is inadequate for comprehensively capturing the long-term evolutionary dynamics of corruption or the influence of political election cycles on procurement integrity. Moreover, while the results suggest systemic patterns, they may reveal inequalities when applied to other procurement sectors, such as infrastructure or healthcare. The possibility of algorithmic exclusion, where the digitization of processes may unintentionally disadvantage rural SMEs lacking infrastructure or digital competence, is a significant ethical concern for more investigation. These limitations are not deficiencies; instead, they delineate a distinct research agenda centered on sector-specific assessments, participatory design workshops, and longitudinal studies to guarantee a balance between the quest of technological efficiency and the need for fair involvement. This research reframes blockchain as a major catalyst inside a carefully crafted governance framework, rather than as a cure-all. Its true value can only be achieved via deliberate and thoughtful integration with human-centric policy and institutional reform.

VI. Conclusions

The potential of blockchain technology to revolutionize Costa Rica's public procurement system has been thoroughly and critically examined in this study, offering a logical and fact-based assessment that challenges both techno-utopian and institutional-stagnation viewpoints. Utilizing an innovative mixed-methods framework that combined a forensic audit of 14,327 existing procedures, stakeholder ethnography, and a live technical simulation, the study attains a unique result: it transcends theoretical conjecture to deliver a quantified, comparative analysis of blockchain's efficacy relative to the identified deficiencies of the existing SICOP system. The findings show that the technology can change things by making them more efficient. For example, processing times were cut by 37.5%, and there were no more gaps in the audit trail thanks to cryptographic immutability. However, these technical benefits become nearly useless without a corresponding change in the institutional landscape. This is clearly shown by Costa Rica's low Blockchain Adaptability Index score of 4.2/10 and the major cultural, legal, and technical barriers that were found.

The study's principal theoretical contribution is in its enhancement of the human intermediation dilemma [17]. It shows that blockchain doesn't get rid of corruption; it only moves it. It is no longer open to human manipulation of documents and processes; instead, it is open to more sophisticated digital areas including collusion before an auction, customizing specifications, and algorithmic bias. This finding changes the role of blockchain from an autonomous solution to a tool that speeds up the process of fighting corruption. Its effectiveness is optimized only when its execution is strategically aligned with institutional reforms, a conclusion strongly corroborated by game-theoretic modeling, which indicates that a hybrid approach—combining blockchain with legislative modernization (Law 7494) and capacity-building—results in a 42% decrease in corruption, representing a 133% enhancement compared to a technology-only strategy.

This work offers three essential contributions: to theory, to practice, and to research. In theory, it shows how to use institutional isomorphism and cryptographic audit protocols together to create a framework for institutional cryptography. This framework may be used to create a model that can be used to test how ready technology is in mid-income democracies. It is the first cryptographic forensic proof that there are concerns with the integrity of data in Costa Rica's procurement system. SHA-256 hashing demonstrates that 12% of SICOP records were altered after they were created. In reality, it provides policymakers a clear, actionable path forward by giving them a staged implementation roadmap with costs that spans from Hyperledger Fabric testing in 2024 to statewide adoption by 2028. This involves making budget estimates and measuring effects that are in accordance with the SDGs.

There are obvious and urgent policy implications for Costa Rica at this time. To make smart contracts and cryptographic signatures legitimate, Articles 12 and 34 of Law 7494 need to be changed. This would address the big legal-technical gap that is now impeding automation. At the same time, it is vital to create a cryptographic audit unit inside the Contraloría General de la República (CGR) so that the monitoring capabilities presented in this study become a part of the organization. To stop algorithmic exclusion and make sure that everyone can take part in the new digital procurement ecosystem, it is also very important to have targeted capacity-building programs made with groups like Promotora de Comercio Exterior (PROCOMER) that focus on women-led and rural SMEs.

Future research should build on this foundation to explore longitudinal dynamics, particularly the impact of political cycles on technology uptake and corruption tendencies. Sectoral expansion into health procurement and municipal contracting will evaluate the generalizability of the proposed framework, while technological integration with AI-assisted anomaly detection presents a feasible method for enhancing the proactive functionalities of a blockchain-based system. This study suggests that the future of anti-corruption programs lies not in a conflict between technology innovation and institutional transformation, but in their deliberate and comprehensive integration. To progress, contemporary society must dedicate itself to the development of socio-technical systems in which cryptography expertise is a crucial component of human-centered governance. This research has worked very hard to make this balance evident.

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