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Citizens' Perception of Blockchain-Based E-Voting Systems: Focusing on TAM

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Abstract: Digital transformation and new technologies have made people's lives easier and led to great results in most areas of business and society. Implementing blockchain technology is one of the best tools for establishing sustainable smart cities and societies. In terms of sustainable governance sophisticated and secure voting systems are necessary to achieve high integrity and transparency and null election fraud, and, in environmental sustainability, e-voting systems eliminate the mass waste of paper and transportation gas emissions; namely, e-voting systems are eco-friendly with high democratic outcomes. Blockchain technology can revolutionize e-voting by increasing the security and transparency of the voting process. Integrating artificial intelligence (AI) and machine learning (ML) into blockchain-based e-voting systems further augments their effectiveness. AI algorithms can analyze voting patterns and detect irregularities, supporting the prevention of fraudulent activities and coercion. ML procedures can enhance voter authentication processes, improve accessibility for diverse demographics, and optimize the productivity of blockchain networks during peak voting periods. This study focuses on understanding citizen perceptions of blockchain-based e-voting in a smart city context using the Technology Acceptance Model (TAM). The study's results indicate that perceived ease of use and perceived usefulness are important factors in determining citizens' intentions to use blockchain-based e-voting. Furthermore, trust in the technology and perceived security were found to influence the usefulness of blockchain-based e-voting positively. This study provides important insights for policymakers and technologists seeking to promote the adoption of blockchain-based e-voting systems in smart cities. The findings of the research supported the research model with positive results. In conclusion, our research model encourages the adoption of a blockchain-based e-voting system to enhance the future voting environment.

Keywords: digital transformation; e-participation; e-voting; blockchain technology; transparency; AI-powered voter registration; ML integration data analysis

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1. Introduction

The development of smart cities and digital transformation in all fields of society have become a global trend in both developed and developing countries. Technological investment in human and social resources and information and communication technologies (ICTs) in both the public and private sectors bring gradual socio-economic growth and the efficient use of existing funds [1]. Due to Industrial Revolution 4.0 standards, smart or e-governance has been on the agenda to tackle urban issues with transportation, the environment, government services, social–economic matters, safety, energy, and the management of urban resources [2]. Over the last two decades, most countries have implemented electronic government systems to deliver public services and support citizens' participation during public decision making under the United Nations Development Programs and using their methods. Even though some countries have failed to adopt digital transformation, smart or e-government enables citizens to participate in social, economic, political, and administrative decisions to create a sustainable government [3]. Citizen participation in urban development matters and vital national events is the most crucial factor in innovative governance, so that people can express their wishes, needs, demands, and voices in city development and their choice of government leaders [4].

As the government regulates and provides public services, governments are the main responsible body in developing e-government services, legally and technically. Moreover, governments should encourage citizens to take part in public decisions and receive public services via e-government services [5]. The accomplishment of e-government services facilitates citizens' participation in political and legislative issue discussions and policy-making processes [1]. Governments have adopted new information and communication technologies to improve organizational control and provide better and more integrated services to citizens and companies to improve communication and to enhance democracy through digital transformation [6]. E-voting is also one of the main parts of e-government services [7,8], and citizens can participate, with digital authorization, regardless of their residency location by using convenient electronic devices, rather than visiting polling stations holding traditional paper-based ballots, standing in a long queue, and wasting time [9,10].

Elections are important political events for nations, and voting is a fundamental feature of human democracy. Voting allows citizens to demonstrate their opinions and decisions by participating in democratic processes [11]. In turn, the use of transparent and technology-based voting methods in the fourth industrial revolution period are fundamental civil liberties and rights in any society, regardless of the democratic level of the country [12]. Otherwise, unfair elections may lead to an increased nepotism and the spread of corruption and government authorities may protect the interests of lobby groups rather than public opinions. Unfortunately, these administrative weaknesses lead to severe socio-economic problems, widespread social inequality, and corruption throughout the country. Consequently, the widespread corruption and social inequality caused by unfair elections lead to long-term catastrophic economic and social consequences. However, democratic and fair elections are crucial for economic development [13] and strengthen a country's credibility and foreign direct investment profile. As digital transformation is a valuable platform for socio-economic development [14], and e-voting is a key component of the e-government systems which enable democratic elections [9], democratic elections and transparent voting methods are very important for every stakeholder in elections, including the government and its citizens.

Most western observers and democratic institutions are skeptical of election statistics in some former Soviet Union countries [15–17]. Some international observers indicated violations of election regulations like vote-splitting, duplicate casting, or ballot stuffing election frauds during the elections in their reports. Consequently, electoral systems that permit voting frauds also complicate the auditing of election results [15]. Since transparent and fair elections are considered an important basis for political stability and economic growth, the electoral processes in a country are closely monitored by all international organizations and financial institutions.

Uzbekistan is also a former Soviet Union country, and its government has been trying to transform its government management methods by implementing ICT-based e-government services in most government institutions over the last two decades, to eliminate corruption and the waste of hard resources, to decrease the mass usage of electricity by public authorities, and to provide fast and convenient public services. However, there is still a critical sector in which to implement e-services, which is the central base of the government's formation. Uzbekistan's elections are criticized by developed countries and democratic institutions because of their paper-based electoral system and cases of the falsification of election results [1,16,17]. The existing paper-based voting system in Uzbekistan causes numerous drawbacks and inconveniences regarding voter authenticity and participation, as well as hindering the security and transparency of election outcomes. In turn, more than three million (about 15% of total voters) potential voters reside in countries such as Russia, the USA, Turkey, South Korea, countries in the EU, and other foreign nations, primarily due to their career, educational, and business activities. The migration of citizens negatively affects election costs, while, on the other hand, the paper-based voting system fails to encompass all voters' locations due to financial and geographical limitations. Therefore, With the implementation of blockchain technology and AI-powered techniques, decentralized and transparent voting methods address existing challenges related to election integrity, voting security, and financial concerns. E-voting is becoming more popular with governments worldwide, and some countries use e-voting systems in national elections instead of the traditional paper-based voting method [8]. In turn, the population of Uzbekistan has been rising sharply and approached 37 million in 2024, whereas it was 20 million in 1991 after its independence. The rising migration trend globally and the growing population compel the Uzbekistan government to introduce e-voting systems, with the objectives of reducing election costs and enhancing the accuracy and security of voting results. Accordingly, the government is also supporting and accelerating the digital transformation of e-government services to create easy access and qualitative public services regardless of time and location. The e-government data depicted in Figure 1, which highlight the developmental trends of Uzbekistan's digital transformation, are derived from the United Nations E-Government Knowledge Base.

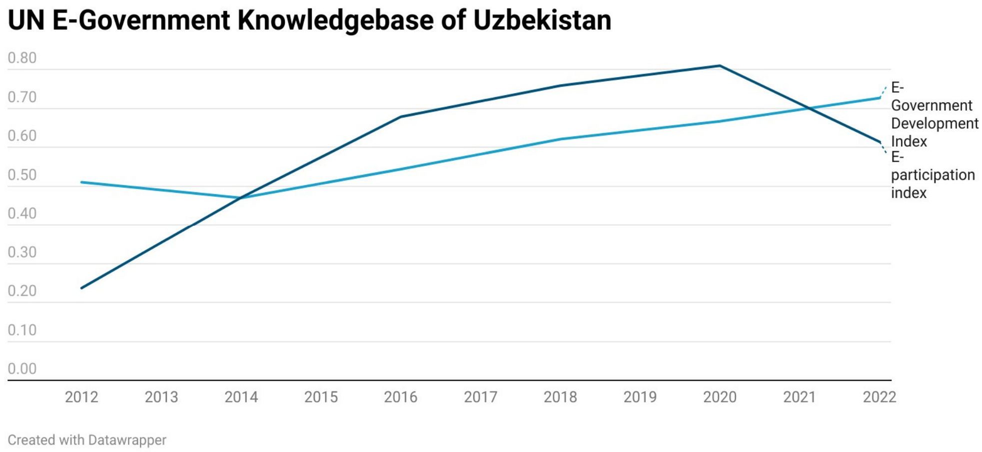

Figure 1. The E-Government Knowledgebase of Uzbekistan between 2012 and 2022.

There is a good chance that the government and its citizens can communicate online and participate in public decisions via e-government services. Why should citizens not enjoy using e-government to express their opinions in elections, when the current Uzbekistan government is trying to build a transparent and inclusive society? To encourage citizens' participation in the allocation and targeted spending of the state budget, the government introduced the OPEN BUDGET voting project in 2021 so that people could participate in voting to finance local social projects related to infrastructure and social services. As the OPEN BUDGET online voting system became very popular among citizens, it can be said with confidence that the transition to an e-voting system for political processes will bring society to another new stage of democratic reforms.

Remote e-voting has recently been considered an important research topic, especially after the COVID-19 pandemic [18]. Some countries have implemented centralized e-voting systems for small-scale elections. However, these centralized systems have several vulnerabilities regarding their risk of attack, tampering with tallying, and audit-related needs. The successful use of blockchain in various fields has caused the implementation of blockchain technologies in government services including the national budget, voting, health, and notary systems as well [19,20]. Scholars have investigated the use of blockchain-based e-voting systems in recent years to overcome these challenges. Because blockchain is a decentralized, secure, and transparent digital ledger that can record transactions across a network of computers, it operates on a distributed system, where every node in the network has a copy of the ledger, and updates are made through consensus among participants. It eliminates the need for intermediaries, reduces the risk of fraud and tampering, and ensures that transactions are transparent and easily auditable [21–23].

This paper investigates citizens' perceptions and attitudes toward adopting a transparent and immutable blockchain-based e-voting system which enables each citizen to vote, regardless of location, under security- and privacy-guaranteed systems. This research explores the influencing factors that encourage voters to use innovative voting methods. This research was conducted using the Technology Acceptance Model, modified with the external constructs of perceived security and trust in technology and the government to support citizens' approach to the usefulness and ease of this e-voting system. This research will support government officials and academic communities in understanding the importance of technology-based e-voting systems and implementing transparent voting methods soon.

The remainder of the study is structured as follows: Section 1 presents the introduction to the research; Section 2 describes the literature review and hypothesis building; and, in Section 3, the research methodology, data gathering, and data analysis are detailed. Section 4 demonstrates discussion and implications. Section 5 is devoted to conclusions.

2. Literature Review and Hypothesis Development

2.1. Blockchain Technology

Since the introduction of blockchain technology by Satoshi Nakamoto in 2008 [24], it has created substantial value, especially in the Industrial Revolution 4.0 period; blockchain technology has been implemented in all services including the financial, health, transportation, and supply chain sectors, and in government and administrative services as well. Blockchain technology is based on a decentralized public ledger and Proof of Work under a consensus protocol [24–26]. The significance and reputation of blockchain technology boomed in the global market after the sharp increase in the Bitcoin and Ethereum cryptocurrencies during the COVID-19 pandemic. Blockchain technology has significantly conquered major industries [27]. Bitcoin enables transactions without traditional "intermediaries," like central banks [28]. Why is blockchain technology occupying the global market and threatening traditional services? Its decentralized, immutable, transparent, and high privacy characteristics attract all industries and government authorities as it strengthens the belief among people, with higher user satisfaction, in fashionable society [29]. Blockchain technology works through a combination of P2P networks, cryptographic encryption algorithms, distributed digital data storage, and decentralized consensus mechanisms. Each block incorporates information from the preceding block, ensuring data immutability throughout the entire chain.

There are four types of blockchain: public blockchain, private blockchain, hybrid blockchain, and consortium blockchain. Each type has distinct advantages and disadvantages that support the user's needs in accomplishing a project or resolving an issue. Public blockchain is open source; anyone can join the blockchain platform as an official node and carry out transactions without any restrictions. This type of blockchain is called "transparent", but it uses a lot of power and takes a long time to scale [30–32]. A private blockchain is only authorized; a limited number of executive staff members can control a private blockchain. This blockchain performs transactions faster than public blockchains [30–32]. A hybrid blockchain has both public and private blockchain characteristics, allowing one to see specific information while the system is controlled privately. For instance, medical records might be saved in a hybrid blockchain, which offers high performance and security at a lower transaction cost [30–32]. A consortium blockchain is a private blockchain that only a particular group can access, and this avoids the risks that come with a private blockchain that a single institution control [30–32] (Figure 2).

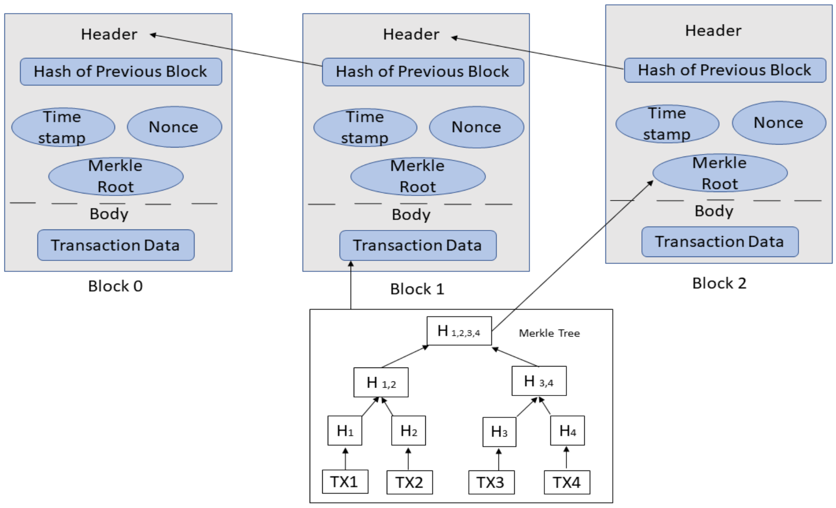

Figure 2. The structural architecture of blockchain data storage [33].

Blockchain technology works under a consensus mechanism, a vital feature of the technology that enables it to maintain a secure and consistent ledger across all nodes in the network. There are more than thirty consensus algorithms in blockchain technology. The choice of a consensus method is based on several factors, such as the size and structure of the network, the type of application it is being used for, and the level of security and efficiency needed. The Proof of Work (PoW) [15,30,31,34], Proof of Stake (PoS) [15,30,31,35,36], Practical Byzantine Fault Tolerance (PBFT) [30,35,37] Proof of Elapsed Time (PoET) [30,35], and other popular consensus mechanisms have been used in most blockchain platforms and services, including e-voting systems.

2.1.1. Blockchain-Based E-Voting

As previous studies have investigated, several blockchain-based e-voting systems use different blockchains. Unlike traditional paper ballots and centralized electronic voting systems, a blockchain-based voting system lets people vote in a way that is open, verifiable, auditable, secure, and very accurate, regardless of where they are, what time it is, or what language they speak. Researchers in this field have developed fair voting systems aimed at increasing voter turnout, preventing electoral fraud, and achieving transparent voting results. Electronic voting is a technique that uses electronic devices instead of traditional paper ballots. Paper voting has the disadvantages of requiring voters to travel to a specific physical site and incurring significant time and financial expenditures in printing, transporting, storing, and counting the voting papers. The current paper voting system poses several issues in terms of fraudulent voting.

In some cases, boxes of fake ballot papers prepared in advance replaced real ones, and the results were faked [15,37–39]. Election openness is increasingly being questioned and compromised in many nations [21]. Because of the rapid development of technology, the vast movement of people, and the demand for movement, many nations have created a broad range of election systems that employ cutting-edge technologies to allow all residents to vote efficiently and accurately [12]. E-voting systems provide both voter and state election authorities. Among the issues with e-voting technology is security, which is an essential consideration for voters and election administrators. The CIA's triad of confidentiality, integrity, and availability has been defined and primarily regarded as the essential principles of information security [40].

Blockchain has been highlighted as an example of a safe technology utilized in online participation services [41]. A blockchain is cryptographically protected. It employs peer-to-peer networking. This blockchain is a distributed, shared ledger amongst network peers, and each peer has a public–private key pair [42]. A blockchain-based e-voting system can improve e-voting security while protecting each voter's privacy. This electronic voting mechanism is decentralized and does not rely on human trust. Registered voters can vote via internet-connected technological devices. All voting records will be made public and can be confirmed by any authorized personnel, nobody can alter the e-voting process [43,44]. Blockchain-based voting systems work with the security characteristics of blockchain technology, which provide a sophisticated, secure, confident election process and transparent results for turnout and casting. Most scholars have described and explained the importance of each characteristic of the blockchain-based voting system and suggested models or protocols with preferred additional features [31,32,34,43,45–50]. Blockchain-based e-voting systems use the security characteristics of blockchain technology to prevent multiple voting and tampering with voting processes and, in turn, ensure secure and transparent casting for authorized voters and record turnout and tallying results accurately in a decentralized, immutable ledger [51]. The blockchain-based e-voting system enables citizens to participate in elections through electronic devices, gaining authorization with a public key and voting anonymously with their cryptographic private key. Nobody can affect others' voting process or results. In turn, voters can verify the inclusion of their votes in the final tally, and the entire voting process becomes subject to audit, as illustrated in Figure 3.

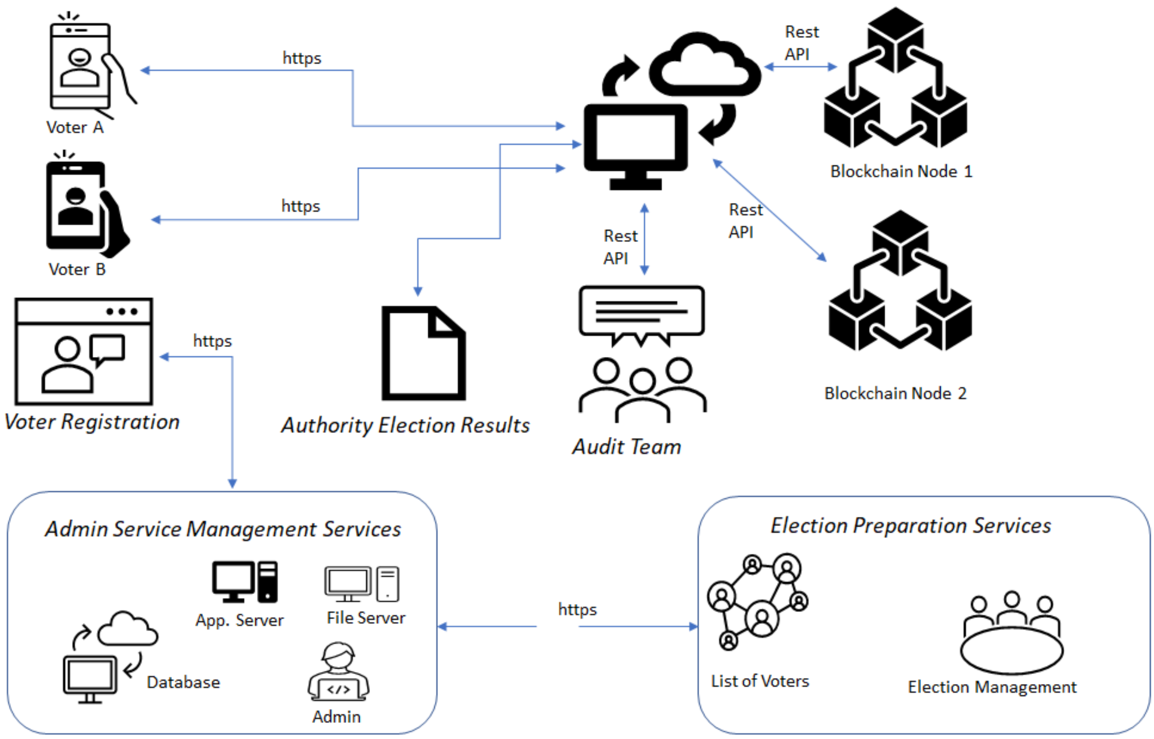

Figure 3. Blockchain-based e-voting framework [31].

2.1.2. Blockchain-Based E-Voting Systems in Use

Some countries have implemented blockchain-based e-voting systems in their local or national elections. All e-voting systems endeavor to strengthen integrity, transparency, privacy, accuracy, and fairness in society. Most of these blockchain e-voting systems are established by private or government organizations, and most of them have brought excellent outcomes, provided fair election results, and decreased election expenditures. Nevertheless, this voting system has been hard to use in some countries because the infrastructure needed to be better, and the electoral staff required more skilled professionals to use these systems effectively [52–54]. In turn, there were challenges in its utilization in terms of a lack of legal base, low ICTs skills, a lack of talented blockchain staff, and intentional challenges like booth capturing and rigging, ballot stuffing, and other purposely performed frauds by the election commission [37]. For instance, e-voting technologies such as FollowMyVote, Agora (used in Sierra Leone in 2018), Voatz (deployed in Virginia in 2018 and 2020), Polyas (implemented in Germany in 2016), Polys (utilized in Moscow in 2020), Luxsoft (operating in Switzerland), KVoting (tested in the Republic of Korea in 2022), and i-Voting (implemented in Estonia in 2005) have been employed in regional or national electoral processes. These systems have provided valuable experiences in blockchain-based e-voting for the global community. Significantly, Estonia's adoption of e-voting has played a critical role in strengthening transparency and democracy and Estonian e-voting system is widely acknowledged on an international scale [12,37,55–58].

2.2. Technology Acceptance Model

The Technology Acceptance Model (TAM) was developed by Davis in the 1980s as a framework to predict the adoption of new technologies by individuals. TAM has been widely used in research to understand the factors that influence people's acceptance and adoption of new technologies, including information and communication technologies (ICTs) such as e-voting systems. The model focuses on user's perceptions of the usefulness and ease of use of a technology, as well as the external factors that may influence its adoption [59,60]. TAM is a framework widely used to understand how individuals adopt and use technology [40]. It explains the determining factors that impact an individual's decision to accept a technology [61]. TAM helps researchers and practitioners to identify why a particular technology or system may be acceptable or unacceptable and to take appropriate measures based on these insights [59]. The model is based on two key components: perceived usefulness and perceived ease of use. These concepts predict a user's intention to adopt technology [59,62]. TAM is an effective tool for comprehending voters' technology adoption choices [61]. According to Davis (1989), the utilization of information and communication technology (ICT) is influenced by its perceived usefulness and perceived ease of use. Perceived usefulness evaluates a person's belief in the ability of a system to enhance job performance, while perceived ease of use evaluates a person's belief in the system's simplicity. The attitude towards use considers a person's internal beliefs and attitudes towards the technology [59,63]. TAM strongly emphasizes the importance of user acceptance and behavior toward new technologies and TAM's main elements, such as perceived usefulness and ease of use, significantly mediate the behavior of internet system users [64]. To ensure the success of a new system's deployment, the TAM model provides valuable insights for making informed decisions. Moreover, Taherdoost and Gao and Li proved that this is the most appropriate model for analyzing technology's acceptance in detail in their studies [65,66].

Overall, the Technology Acceptance Model has proven to be a valid and reliable model for explaining the acceptance and use of information systems and technologies. Its application has been expanded to various technologies, including blockchain-based e-voting and has helped researchers and practitioners to better understand the factors that influence user acceptance and adoption of new technologies [64]. Accepting blockchain technology is complex, and relying solely on the TAM model may provide a partial solution. Therefore, combining the TAM model with other relevant constructs is recommended to better understand a contemporary blockchain-compatible model [27]. The model can become stronger with external variables used to support the core constructs of TAM. These external variables reflect individual variances, situational constraints, and predictable management actions [63], and additional variables would assist in obtaining better effects [27]. The researchers expanded upon the foundational TAM model, integrating perceived usefulness (PU), perceived ease of use (PEoU), attitude towards use, and intention to use, with the addition of the external variable of trust and a new construct termed perceived security. This new construct explains the primary security attributes of blockchain-based e-voting systems, aligning with the objectives of this study (Figure 4).

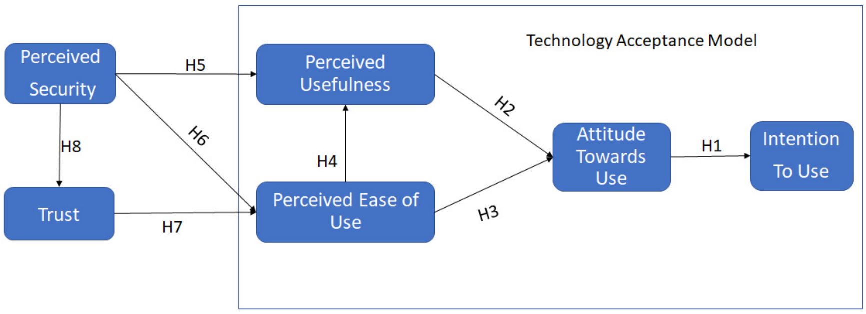

Figure 4. Proposed research model.

- Behavioral Intention to Use

Behavioral intention refers to a user's inclination or readiness to carry out a particular action within a system, influenced by their personal motivations and reasons. It is essentially about why users plan to use and embrace a technical system, which in turn shapes their intention to engage in specific behaviors. In the context of technology adoption, behavioral intention plays a crucial role in understanding users' willingness to accept and use emerging technologies and reflects users' subjective motivations and perceptions regarding a system, influencing their likelihood to engage in specific behaviors. This intention reflects the user's assessment of how probable or inclined they are to participate in a particular behavior, especially when it comes to accepting and adopting new technologies [27,62].

- Attitude

Attitude refers to a person's overall evaluation or appraisal of a particular object, person, situation, or concept, such as a new technology. Attitudes can be positive, negative, or neutral and can influence a person's behavior and decision-making [59,62]. Attitude towards use significantly impacts one's intention to use blockchain-based e-voting. It means that if citizens have a favorable view of a technology, they are more likely to intend to use it.

H1. *Attitude towards use has a positive impact on intention to use.*

- Perceived Usefulness

Perceived usefulness embodies an individual's evaluation of the potential advantages gained from employing a technology or system to improve their job performance or task efficiency. Essentially, it reflects the extent to which a person perceives technology as beneficial in accomplishing their aims and objectives. This perception holds significant weight in the adoption of new technology, as individuals are inclined to embrace technology if they perceive it as constructive in fulfilling their needs and ambitions [27,59,67].

H2. *Perceived usefulness has a positive impact on attitude towards use.*

- Perceived Ease of Use

Perceived ease of use represents the user's appraisal of the level of simplicity involved in acquiring proficiency and effectively utilizing a product, including software applications or websites. It measures the perceived level of user-friendliness of a product and can significantly affect user satisfaction and adoption rates. This perception is complexly shaped by various factors, including the design of the user interface, the availability of assistance and documentation, and the coherence and simplicity of the overall user experience [8,62,68].

H3. *Perceived ease of use has a positive impact on attitude towards use.*

H4. *Perceived ease of use has a positive impact on perceived usefulness.*

- Perceived Security

The TAM model suggests that perceived security is a key determinant of a user's willingness to adopt and use new technology. Perceived security refers to a user's belief about the level of protection against security threats (such as hacking and data loss) provided by a technology [9,69–72] Most of the review papers illustrated the security characteristics of blockchain-based e-voting systems, and this factor affects users' ease of use and perceived usefulness, therefore, perceived security was regarded as external variable.

H5. *Perceived security has a positive impact on perceived usefulness.*

H6. *Perceived security has a positive impact on perceived ease of use.*

- Trust

Trust in technology represents a person's belief that a particular technology or system will perform as expected, be secure, and protect the user's privacy. Trust in government indicates the belief and confidence of citizens in the ability, fairness, and integrity of government institutions and leaders to make and enforce decisions that serve the public interest [8,69,73].

H7. *Trust has a positive impact on perceived ease of use.*

H8. *Perceived security has a positive impact on trust.*

3. Research Methodology

3.1. Sampling and Data Collection

The fundamental purpose of this research is to examine citizens' perception of blockchain-based e-voting and to analyze the primary factors affecting voters' behavioral intention to use this e-voting system. A Google Forms-based survey was distributed to citizens on social media, especially telegram and Facebook groups in Uzbekistan, to assess online-active people's opinions. A total of 387 respondents participated in the questionnaire; regarding gender, 286 (72%) respondents were males, and 101 (28%) respondents were females, respectively. By age category, people aged between 18 and 29 (54.5%) and 30 and 39 (27.6%) years were active online. In the education sector, individuals holding a bachelor's degree (55.8%) and a master's degree (19.9%) were more active online. Regarding career interests, students demonstrated a higher engagement, with 39.5% showing significant online activity. Employees in Public Government Entities and the private sector presented similar levels of attention to online activities, each at approximately 21%.

The questionnaire consists of five demographic questions, including gender, age, education, career, and degree of ICT skills, and the other twenty-one questions are based on measurement items of the TAM and external independent variables. The perceived security of blockchain-based e-voting system and trust in government support variables are used to make the research more comprehensive and to analyze how these outward constructs encourage users to accept new voting systems. Respondents were asked to answer questions on perceived security, their trust in technology and the government, and other TAM model characteristics influencing users' behavior to use new technology. The construct items of the research model were assessed on a five-point Likert scale (interval scale) ranging from 1 (strongly agree) to 5 (strongly disagree). The survey questionnaire was held in the Uzbek language, and the authors evaluated the results in English.

Statistical Technique

To analyze the research data and test hypotheses, the Partial Least Square-Structural Equation Modelling (PLS-SEM) method was chosen, and the collected data were analyzed through Smart PLS. As this method is a nonparametric statistical method, it is not necessary to supply data normally. It also helps assess structural models that involve several constructs and verify predictor variation [10,74]. PLS trajectory modeling is a comprehensive SEM approach for factorial and composite models that assesses constructs, estimates structural models, and conducts model fit tests [75]. PLS-SEM is considered a suitable approach for this study since the primary aim of the research is to predict and explore new experiences in the voting system [75–77]. PLS-SEM can analyze measurement models, including factor loadings, reliability (Cronbach's Alpha, composite reliability), Construct validity (Convergent validity, Discriminant validity (i. Fornel and Larcker Criterion, ii. HTMT Ratio)) and structural model VIF values, R-Square, Q-Square, and Hypothesis in the one model [77,78]. A version of Smart PLS 4 (Smart PLS GmbH, Bönningstedt, Germany) was used to analyze the data and analysis performed in this study.

3.2. Data Analysis

Analyzing a Confirmatory Factor Analysis (CFA) involves assessing the fit of the measurement model and the validity of its latent constructs. In this study, we utilized Smart PLS to analyze survey data. We evaluated factor loadings to gauge the strength of the relationships between latent constructs and the observed variables. Factor loadings exceeding 0.70 were deemed acceptable, indicating a substantial contribution to measuring the underlying construct. We also assessed reliability using composite reliability or Cronbach's alpha, aiming for values above 0.70 for satisfactory internal consistency. Additionally, we examined discriminant validity by ensuring that the squared correlations between latent constructs were lower than the average variance extracted (AVE) for each construct, affirming their distinctiveness [27,74] (Tables 1 and 2).

Table 1. Descriptive statistics of demographic information.

Variable	Category	Frequency	Percentage
Gender	Male	286	72
	Female	101	28
	Total	397	100
Age	18–29	211	54.5
	30–39	107	27.6
	40–49	44	11.4
	50–59	18	4.7
	60 or Older	7	1.8
Education	High school	66	17.1
	Bachelor	216	55.8
	Master	77	19.9
	PhD	28	7.2
Career	Student	153	39.5
	Entrepreneur	49	12.7
	Public Government Entities	83	21.4
	Private sector	82	21.2
	Unemployed	20	5.2
Degree of ICT skills	Low	0	0
	Basic	6	1.6
	Intermediate	37	9.6
	Good	150	38.8
	Very good	194	50.1

Table 2. PLS-SEM assessment results of measurement models (reliability and validity).

	Convergent Validity		**Consistency Reliability**	
Indicators of Constructs	Loadings	AVE	Composite Reliability ρc	Cronbach's Alpha
	0.70	0.50	0.70	0.60–0.95
Eligibility (PS1)	0.804	0.679	0.937	0.921
Uniqueness (PS2)	0.848			
Privacy (PS3)	0.825			
Accuracy (PS4)	0.857			
Verifiability (PS5)	0.84			
Robustness (PS6)	0.808			
Fairness (PS7)	0.781			
Trust in Technology (Tr1)	0.917	0.767	0.868	0.704
Trust in Government (Tr2)	0.833			
PEoU1	0.913	0.816	0.947	0.925
PEoU2	0.906			
PEoU3	0.913			
PEoU4	0.882			
PU1	0.869	0.793	0.939	0.913
PU2	0.874			
PU3	0.911			
PU4	0.907			
ATU1	0.959	0.923	0.96	0.917
ATU2	0.962			
ITU1	0.967	0.937	0.967	0.933
ITU2	0.969			

3.2.1. Reliability Analysis

As seen in Table 2, the factor loadings, average variance extracted, composite reliability, and Cronbach's alpha results are greater than the recommended ratios and the results demonstrate strong reliability. The constructs' measurements of the research model show that the sub-contracts are reliable, and their latent variables are valid to the research model [76,78].

3.2.2. Discriminant Validity

In the evaluation of discriminant validity (Table 3), scholars commonly advocate for the heterotrait–monotrait (HTMT) method due to its recognized robustness in yielding precise outcomes. Discriminant validity can be calculated using the square root of the AVE or by comparing the shared variance between factors with the square root of the AVE. The square root of the AVE of a construct must be greater than its correlation with another construct, namely if the correlation coefficients between the variables passed the significance tests at the 0.01 level, its discriminant validity is considered satisfactory [79,80].

Table 3. Discriminant validity—heterotrait–monotrait ratio.

	ATU	ITU	PEoU	PS	PU	Trust
ATU						
ITU	0.777					
PEoU	0.822	0.838				
PS	0.823	0.747	0.893			
PU	0.795	0.753	0.845	0.837		
Trust	0.825	0.831	0.889	0.938	0.881	

This approach is esteemed for its superiority over alternative techniques such as cross loadings and Fornell–Larcker measurements, offering a thorough assessment of the differentiation among latent constructs. Scholars typically recommend that the HTMT ratio fall within the range of 0.85 to 0.9; if the ratio surpasses 0.9, it suggests an excessive similarity between constructs, indicating a lack of differentiation [74,80]. Only the perceived security and trust coefficient is slightly greater than the recommended value, and this means that these two constructs are a little bit closer (Figure 5).

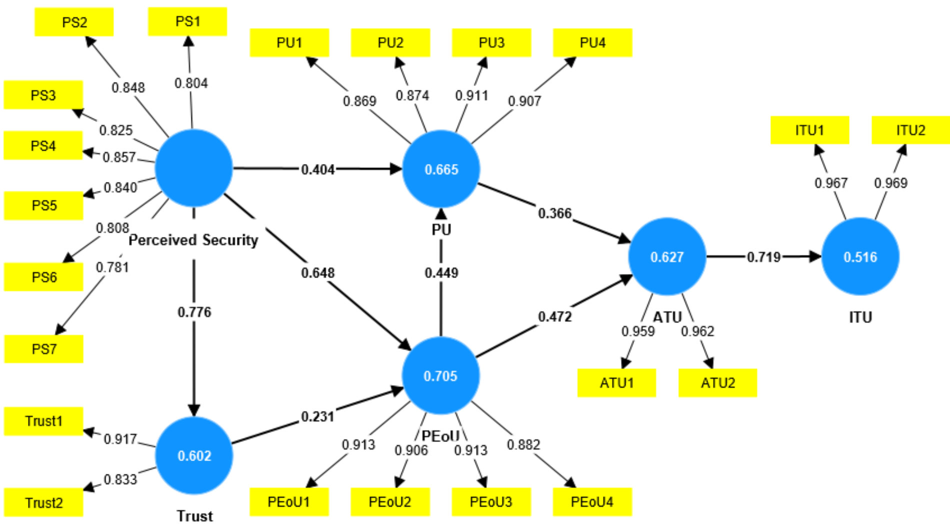

Figure 5. Structural equation modelling results.

The structural equation modelling results demonstrate that the H1, H6, and H8 path coefficients are more than 0.6, which is stable and acceptable. As the results showed, perceived security has an important impact on trust (0.766) and PeOU (0.648), respectively. The attitude towards to use also correlated with a positive impact (0.719) on intention to use.

4. Discussion and Implications

4.1. Discussion

This research describes the analysis of citizens' perception of a blockchain-based e-voting system, and the findings support the proposed research model accordingly. The relationships between the variables and the proposed designs positively affect people's intention to use new voting technology.

Convergent validity indicators, including loading (>0.7) and average variance extracted, AVE, (>0.5), resulted in higher than required minimum rates, and this implies the validity of the research model and encourages the implementation of blockchain-based e-voting systems for eligible users in Uzbekistan. The reliability results also showed positive and higher indicators than the demanded minimum rate. The composite reliability ρc is higher than 0.7, and Cronbach's alpha result is more than 0.6 for all construct parts.

The research hypotheses were analyzed effectively, and their impacts were proved, with positive results: H1. attitude towards use impacted intention to use at 0.719, H6. perceived security influenced perceived ease of use at 0.648, and H8. perceived security affected trust at 0.772 had the greatest results.

4.2. Implications

To achieve this objective, the researchers used the Technology Acceptance Model (TAM) as the theoretical framework, which suggests that the intention to adopt technology is influenced by two key factors: perceived usefulness (PU) and perceived ease of use (PEOU). This research aimed to identify the relationships between these factors and the intention to adopt e-voting systems and to explore the impact of other relevant variables, such as trust in the technology and previous experience with e-voting.

4.2.1. Implications for Research

The theoretical implications of the citizen perception of blockchain-based e-voting systems are important for understanding the adoption of new technology in general and e-voting technology in particular. Our findings can contribute to developing and refining technology acceptance models, such as the Technology Acceptance Model (TAM), by providing empirical evidence of the factors influencing the intention to adopt e-voting technology. The theoretical implications of citizens' perception of blockchain-based e-voting systems are significant, as they can advance our understanding of technology adoption and inform the development of new and more effective technologies for democratic processes. This study encourages research on e-government and e-voting in Uzbekistan and leads to better insights into analyzing technology implementations and user acceptance. The use of the Technology Acceptance Model (TAM) as a theoretical framework can be valuable in understanding citizens' perceptions of new technology in the context of smart cities. Future research can build on this study's findings by examining other factors that may influence citizens' acceptance of blockchain-based e-voting systems, such as privacy concerns, accessibility, and usability.

4.2.2. Implications for the Future

This study interprets the current Uzbekistan voting case and assesses the readiness of its citizens to accept technology-based and AI-powered voting systems in future elections. The practical implications of citizens' perception of blockchain-based e-voting systems are significant, as they can inform the design, development, and implementation of e-voting systems, as well as influence the likelihood of their adoption by citizens. For example, suppose the research results show that citizens are concerned about the security and transparency of blockchain-based e-voting systems. Technology developers can address these concerns by implementing stronger security measures and making the technology more transparent. Additionally, the research results can inform the development of policies and regulations related to e-voting technology. This study's findings suggest that blockchain-based e-voting systems can be an effective and efficient way to participate in the democratic process. Citizens should be encouraged to use this technology to exercise their right to vote and engage in democratic processes. However, they should also be aware of the potential risks and limitations of the technology and be vigilant about their privacy and security when using the system.

Consequently, this research has important implications for researchers, policymakers, practitioners, and citizens, highlighting the potential benefits and challenges of blockchain-based e-voting in the context of a smart city. By addressing these challenges and building citizens' trust and confidence in technology, blockchain-based e-voting systems can play a valuable role in enhancing the democratic process and promoting civic engagement. A blockchain-based e-voting system creates value for all stakeholders in the election, providing social equity and convenience for all voters regardless of their language, location, and social status as well [81].

5. Conclusions

The adoption of blockchain e-voting can be influenced by various factors, including the security and transparency of the technology, the perceived benefits of using blockchain for voting, and the availability of supporting infrastructure. Other factors that impact the adoption of blockchain e-voting include cultural and political attitudes toward technology, the perceived level of trust in the technology, and its ability to provide a secure and transparent voting process.

This study examined the main factors influencing citizens' perceptions of implementing blockchain-based e-voting systems in a smart city. To express the core factors affecting e-voting adoption, questions related to trust (trust in technology and trust in government) and the security characteristics of blockchain-based e-voting were also asked to find out users' opinions about the system and deliver some information about the system. A total of 387 respondents participated in the survey, and most supported the research model with positive answers. According to the findings, the perceived ease of use and perceived usefulness are more substantial factors affecting the implementation of blockchain-based e-voting systems. From the citizens' point of view, this research analyzed voters' willingness to use electronic voting technologies.

In turn, government support is the best factor for implementing new technologies. The implementation of new services or technologies requires reasons and needs, respectively. Uzbekistan has administrative and legislative drawbacks to its election processes; therefore, government officials should express political willingness and government support for establishing new innovative and transparent voting systems. It is crucial that the Central Election Commission should demonstrate innovative measures and standards to implement transparent voting methodologies throughout the digital transformation process. The findings of this study also supported the hypotheses that attitude towards use, perceived security, and trust were significant factors in influencing citizens' intention to use blockchain-based e-voting systems. This technology has the potential to improve the efficiency and transparency of the electoral process, enhance citizens' trust in the system, and increase their participation in the democratic process.

The implementation of blockchain-based e-voting system includes AI and ML, and these algorithms strengthen blockchain technology with high productivity. The integration of artificial intelligence (AI) into blockchain-based e-voting systems can significantly enhance various aspects of the electoral process. During the voter registration stage, AI techniques such as facial recognition and biometric identification can be employed to implement robust voter authentication mechanisms, ensuring only eligible voters participate and preventing voting fraud. In the data analysis and auditing step, AI algorithms can analyze vast volumes of voter registration data, ballot information, and blockchain transaction records to detect anomalies, irregularities, or potential tampering instances, thereby enhancing the integrity and transparency of the voting process. AI can also be leveraged to create user-friendly and intuitive interfaces for voters, incorporating features like natural language processing (NLP) for efficient interaction and intelligent assistance, ensuring a smooth and secure voting experience. Crucially, AI can automate and verify the vote counting and tallying process, cross-checking results against immutable blockchain records, ensuring the accuracy and transparency of the final election results. Furthermore, AI-powered systems can monitor the e-voting platform for potential cyber threats, such as distributed denial-of-service (DDoS) attacks, malware infections, or other malicious activities, detecting and mitigating these threats in real time, thus enhancing the overall security of the system. The integration of AI into blockchain-based e-voting systems can significantly enhance various aspects of the electoral process, from voter authentication and data analysis to user experience and cybersecurity, contributing to more secure, transparent, and efficient democratic processes.

Machine learning (ML) can play a pivotal role in enhancing the robustness and efficacy of blockchain-based e-voting systems. ML algorithms can be trained on extensive datasets encompassing voter information, biometric data, and historical voting patterns to develop robust voter verification and authentication models, mitigating the risk of voter imitation and fraud. Additionally, ML techniques can be applied to historical voting data and demographic information to develop predictive models for voter turnout, preferences, and election outcomes, facilitating informed decision-making processes such as resource allocation and campaign strategies. Moreover, ML models can be employed for the continuous monitoring of the e-voting system during and after the election, analyzing data streams and adapting to evolving conditions or emerging threats. This proactive approach can help maintain the system's security, reliability, and integrity throughout the entire electoral process. The integration of ML capabilities into blockchain-based e-voting systems can significantly enhance voter authentication, predictive analytics, and real-time monitoring, contributing to more secure, transparent, and efficient democratic processes.

To sum up, the implementation of this e-voting system ensures eco-friendly voting methods and election procedures, encouraging environmental sustainability. Furthermore, it offers voting security, privacy, and transparency, thereby advancing the election of accountable parliamentary and governmental leaders.

However, this study also highlights the need for policymakers and practitioners to pay close attention to citizens' perceptions of security and their trust in technology. Measures must be taken to ensure the security and integrity of the system and to build citizens' trust in the technology. In summary, the findings of this study provide valuable insights into citizens' perceptions of blockchain-based e-voting in the context of a smart city. This study's results support the potential benefits of this technology in improving the electoral process and increasing citizens' participation in the democratic process.

Limitations and Future Research

This research is theoretical and was conducted following previous studies and analyzed survey data to prove its research model. Future researchers will analyze the technological readiness of Uzbekistan's infrastructure, including its internet penetration, e-readiness, and energy supply. In the case of energy and internet outages, the Helium blockchain would be the best solution in developing countries, supporting the better and faster wireless connection of devices without internet and with low energy consumption, using GPS. Helium blockchain is a suitable platform for smart cities to achieve sustainable governance in their city management and enhance citizen services using secure helium equipment [82,83]. Smart city development requires technological innovation, organizational innovation, and policy innovation measurements to create a sustainable modern smart city [84] and the citizen acceptance of new technologies and innovations is the most important criterion In conclusion, the utilization of blockchain technology, artificial intelligence (AI), and the Internet of Things (IoT) facilitates an analysis of big data and promotes sustainable governance in smart cities, thereby enhancing the quality of life for citizens within secure systems.

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