Transforming e-Participatory Budgeting with Blockchain: Boosting Transparency and Citizen Engagement

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***Abstract*—Integrating blockchain technology into the public sector promotes transparency, accountability, and citizen participation in e-Government services. This study discovers key challenges of the e-Participatory Budgeting (e-PB) model in Estonia using an exploratory case study research method in software engineering. We conducted semi-structured interviews with 16 participants, including local government officials from multiple Estonian municipalities, e-democracy experts, citizens, and IT and/or participatory budgeting (PB) project managers, using a snowball-purpose sampling technique. The study highlights the main issues in existing e-PB systems, such as lack of public deliberation, inadequate tracking of PB funds, low citizen participation, transparency issues, data manipulation risks, and inclusivity concerns. Our findings indicate that the core attributes of blockchain, including decentralization, immutability, traceability, and disintermediation, mitigate these issues. These intrinsic characteristics of blockchain prevent data manipulation risks, facilitate tracking of the status and budget of the PB project, and ensure equal participation, thus fostering citizen trust in the e-PB system. We propose a conceptual model of blockchain-based e-PB that unifies multiple e-PB systems into a single platform. Finally, we discuss the practical implications for engineering managers and policymakers who integrate blockchain-based solutions into e-Governance systems.**

***Index Terms*—e-Participatory budgeting, blockchain, smart contracts, e-Participation, transparency.**

Managerial Relevance Statement

This study provides strategic insight for policy makers and engineering managers by addressing key challenges in the implementation of e-PB. The findings reveal that the existing e-PB models suffer from several issues, including a lack of digital space for public deliberation, inadequate budget tracking, low citizen engagement, data manipulation risks, transparency issues, and inclusivity concerns. Using blockchain technology, we propose a conceptual e-PB model that improves real-time budget monitoring, facilitates P2P public discussion, automates decision-making through smart contracts, and incentivizes citizens through tokenized rewards. The proposed hybrid blockchain model ensures GDPR compliance while maintaining security and accessibility. These insights offer decision makers with a structured approach to the deployment of blockchain in the public sector, increasing trust, efficiency, and greater citizen engagement.

I. Introduction

PARTICIPATORY budgeting (PB) is a democratic process that gives citizens the power to decide how to spend a portion of public funds [1]. PB has the potential to turn citizens into active participants, thereby increasing democratic participation and transparency in budgeting processes [2]. Despite their potential to promote transparency and citizen participation, traditional and current electronic participatory budgeting (e-PB) models suffer from various challenges. These include the risk of manipulation, lack of transparency [3], resistance from local governments [4], and low citizen participation [5] and trust [6]. Other issues include restricted monitoring of the process by citizens [7], and insufficient active citizenship in decision-making processes [8]. One of the biggest challenges in the public sector is the management of centralized e-Government databases that increase the chance of manipulation by public servant administrators [9]. The existing literature identifies these challenges as significant barriers that make the PB less effective and undermine public trust in a democratic process. Given these issues, there is a need to find a robust solution to persistent challenges by exploring innovative technologies such as blockchains to improve transparency, efficiency, and inclusion of e-PB systems. The main motives behind this study are as follows:

- Identify key challenges faced by the traditional e-PB system and address those issues through blockchain technology to promote the effectiveness of e-PB.
- Discover critical factors that demotivate citizens from active participation and collaboration in e-PB processes.
- Fill in the gaps in existing literature related to the specific application of blockchain technology in the e-PB process.
- To advance democratic processes through increasing transparency, citizen participation, and inclusivity using innovative technology.

Blockchain as a distributed ledger technology with its intrinsic features —- decentralization, disintermediation, transparency, traceability, and immutability—offer promising solutions to current problems. By providing a transparent peer-to-peer (P2P) network, the blockchain improves civic engagement and e-Participation [10]. This enables direct interaction between citizens without the need for government involvement [11], eliminates corruption, improves security and service efficiency, and ensures transparency [12, 13]. The use of blockchain in organizations improves transparency, accountability, and security, streamlines organization operations, and reduces costs. However, factors such as organizational readiness, technical expertise, and regulatory compliance need to be carefully planned and considered to successfully implement blockchain [14]. Moreover, blockchain technology reduces

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a variety of challenges faced by traditional e-Governance systems, including internal and external hazards. System failures are caused by internal hazards, such as power outages, hardware failure, software error, network problems, and human error. External hazards include ransomware, denial-of-service attacks, infiltration, and natural calamities [15].

The blockchain is a series of interconnected blocks that facilitate secure storage of transactions on a decentralized network of many computers [16]. Its features include:

- **Transparency:** After reaching a consensus of most nodes on the network, transactions are stored and the ledger is updated, making transactions publicly visible to ensure transparency [17].
- **Immutability:** It ensures that previously validated transactions cannot be altered or removed, increasing trust in the system [18].
- **Traceability:** Information stored on blockchain can be traced back to its origins, facilitating real-time monitoring and information [18]. Increased traceability allows continuous and real-time tracking while avoiding additional network costs [19].
- **Decentralization:** This feature stores all transaction records on a decentralized ledger validated by all nodes participating in the network, rather than storing transaction records centrally, thus increasing transparency and efficiency [18]. This core attribute promotes decentralized decision making and increases trust between stakeholders [20]. In addition, decentralization streamlines the process and reduces cost, making it a suitable choice for public administration entities [21].
- **Disintermediation:** Due to its distributed ledger, this feature reduces dependence on third-party entities such as financial intermediaries [22]. This transforms business processes by creating trust without intermediaries [17], and improves the inclusiveness of service delivery [23].

Smart contracts are self-executing contracts and pieces of computer codes stored on a blockchain, enforced when the terms and conditions are met. These contracts could be used to automate procurement processes such as contract management, identity verification, payment processing, and dispute resolution [24, 25]. The lack of transparency, security, and democratic representation in third parties requires a decentralized solution, which can be provided by blockchain and smart-contract technologies, due to their traceability and transparency features [26]. These technologies reduce the need for trusted intermediaries [27], and improve the digital services provided to citizens and members of the community [28].

The following scenario describes how blockchain technology benefits each stage in a PB process. Imagine that a community is conducting PB to decide how to spend €1 million of their public funds to improve their local facilities. The PB process begins with **budget determination**, where the city council agrees on the amount. This decision is recorded on the blockchain, allowing citizens to verify that € 1 million is the agreed budget. Next, the **proposal submission** phase begins where citizens submit their proposals, for example, creating a public library or improving street lighting. Each proposal is recorded on the blockchain, making it immutable and visible, and allowing other citizens to review and comment on submitted proposals during the **public discussion** phase in a P2P network. This empowers citizens to discuss the proposals that bring about changes and are most beneficial to the community. All comments, suggestions, or proposal ratings are also stored, ensuring transparency in the discussion process. In the **expert evaluation** stage, an expert committee usually consists of up to 10 people from different departments or cities with diverse expertise to evaluate the feasibility of each proposal. Their evaluations are publicly visible and securely stored on the blockchain. Once the proposals are evaluated, citizens proceed to the **voting** phase. This phase allows citizens to cast their votes securely through a blockchain-based system, which is tamper-proof and makes it impossible to manipulate the vote without being detected. Once the vote is completed, the **city council** reviews and approves the winning projects. After the winning projects are selected and the funds are allocated, smart contracts release the allocated funds in stages as the project milestones are met. The blockchain-based system allows the public to track the distribution of the €1 million. All stakeholders in PB, including citizens, can see in real-time when and how money is being spent on each winning project, which ensures accountability and prevents misuse of public funds. Finally, in the **feedback gathering** phase, citizens provide their input to the PB processes, allowing all participants to review the collected feedback that is stored on the blockchain, making it immutable and proof of manipulation. Therefore, we encourage users to provide genuine feedback by ensuring anonymity and ensuring that their feedback cannot be manipulated or altered [29].

Successful applications of blockchain technologies span a diverse range of sectors, including P2P electricity trading services, customs clearance, electronic voting, real estate, copyright protection, notarization, education, among others [30]. Kassen classifies e-Government processes that can be automated using blockchain technology through analysis of four different domains such as e-Healthcare projects, e-Asylum management, blockchain-driven city, and military e-Procurement. These blockchain-based solutions complement the reforms of e-Government by facilitating better databases and improving the transparency of the process, thus addressing the problems associated with a lack of public trust between the network participants [9].

The state-of-the-art shows that transparency depends on the degree of e-Participation. Consequently, in [5], a theoretical framework for e-PB is developed with varying degrees of citizen participation in governance processes. However, there is a gap in the establishment and enhancement of e-Participation, which is characterized by lower citizen participation, inclusivity concerns, and a lack of transparency and trust.

To fill this gap, we pose the following research question. How to develop an e-PB model that uses blockchain technologies to address issues of transparency, inclusivity, and a low participation rate in e-PB processes? For a separation of concerns, we deduce the following three sub-questions.

1) What features integrated into an e-PB model leverage blockchain technologies, significantly increase citizen

participation in the e-PB process?
2) What design elements within a blockchain-driven e-PB model effectively foster more inclusive and decentralized decision-making processes?
3) What blockchain-based model for e-PB enhances citizen monitoring, ensuring a higher level of transparency throughout the participatory budgeting processes?

Several studies explore various technological interventions such as the use of digital tools (DTs) and digital platforms in different economic and cultural contexts, including Italy [2, 31], Spain [32, 33], Russia [34], Serbia [35], Poland [36], Croatia [37], and Belarus [38] to enhance the effectiveness of e-PB. Meanwhile, these studies identify various traditional challenges of PB in different nations, including lack of debate and discussion [31], lack of interest, low citizen participation in the project selection process, and a small amount of e-PB funds [35]. Additional challenges include the lack of reporting on the implementation of PB, poor communication between public servants and citizens [36], and a lack of trust between local authorities and citizens [37]. However, there is a significant gap in the existing literature regarding the application of blockchain technology to address uncovered challenges. The potential of blockchain technology has been confirmed in improving transparency and accountability, enhancing trust, and ensuring security and privacy in various domains such as electronic voting [39], supply chain [40], real estate [41], and education [42]. However, its particular application in e-PB remains underexplored. This study aims to fill this gap by exploring how the use of blockchain technology and its inherent features promote transparency, enhance citizen participation, and achieve greater inclusivity and equal participation in the e-PB process. In addition, the study also identifies various challenges faced by the traditional e-PB model in Estonia. Therefore, this study proposes a novel solution to the persistent challenges faced by traditional e-PB models.

The research method we use is the exploratory case study research method in software engineering, involving semi-structured interviews with 16 participants, including local government officials from different Estonian municipalities, e-democracy experts, IT and/or project managers, and citizens. Through a snowball-purpose sampling technique, we select participants to ensure a diverse representation of perspectives. The selection of 16 participants from diverse demographics ensures that the findings are not limited to a single perspective but rather reflect a broad representation of the e-PB ecosystem. The interview questions were pilot tested to refine clarity and ensure relevance, demonstrating procedural rigor. The interviews aim to discover existing problems in the current e-PB platforms, factors demotivating citizen participation, the importance of design elements, and to gather insights on the perceived benefits of a blockchain-based solution. We analyze the interview data using the R package for qualitative data analysis (RQDA)[1] and apply the thematic analysis method to extract and report topics, thus interpreting the findings.

[1]https://rqda.r-forge.r-project.org/.

The main findings reveal that the application of blockchain technology, with its inherent characteristics, significantly enhances the interest and motivation of citizens to participate equally in the e-PB process. The study identifies several technical and nontechnical challenges, demotivating factors hindering citizen participation, essential design elements for system usability and accessibility, and expected benefits of core blockchain attributes in the current e-PB system in Estonia. It turns out that the use of blockchain technology addresses the issues of low citizen participation, transparency, inclusivity, and manipulation by providing equal participation through a P2P network. This empowers citizens and other underrepresented groups to actively participate in decision-making processes by incentivizing citizens with rewarding tokens, allowing them to digitally discuss proposals, and track the status of ongoing projects and allocated budgets in real time. Therefore, the use of blockchain technology contributes to building trust with citizens and the e-PB system, while also enhancing citizen engagement and collaboration.

Furthermore, the study finding emphasizes that hybrid or consortium blockchains that take advantage of the Zero Knowledge Proof (ZKP) technique provide a good balance of transparency, data privacy, and General Data Protection Regulation (GDPR) compliance. An unexpected result is the identification of a significant gap between idea submission and voting phases, marked by a lack of public discussion, which limits the sense of ownership among citizens and reduces participation. Adding a deliberation phase powered by P2P blockchain communication channels can bridge this gap and foster more inclusive governance. The study also highlights that current practices involving multiple e-PB platforms introduce inefficiencies and increase the risk of manipulation, whereas a unified blockchain-based platform can eliminate these vulnerabilities by automating and securing the entire workflow. Other unexpected finding is that many citizens perceive winning e-PB projects as too small in scale and not addressing community priorities, reducing enthusiasm for future participation. To improve citizen satisfaction and long-term participation, larger-scale projects with larger budget allocations are suggested. Finally, the study finds that young citizens perceive the e-PB systems as disconnected from their interests and feel their voices are not heard, despite their tech savvy. Therefore, designing visually appealing, mobile-friendly interfaces and introducing youth-centric projects can boost engagement among younger demographics.

Our main contributions are summarized as follows.

- We describe how integrating blockchain technology into e-PB unifies disparate e-PB systems into a transparent and inclusive platform.
- We provide real-life examples of blockchain applications in the public sector in different economic and cultural contexts.
- We provide empirical evidence on how various features of the blockchain, such as immutability, traceability, transparency, decentralization, and disintermediation, address the identified challenges. Therefore, building trust among community members and local authorities, improving transparency, increasing citizen participation by reward-

ing tokens, and facilitating P2P discussion space.
- We propose a blockchain-based e-PB model consisting of a set of smart contracts and interaction of the PB steps.

The remainder of the paper is structured as follows. Section II explores the existing literature related to e-PB and blockchain implementations in different contexts. Section III captures the AS-IS state of the running case and presents the research method for this study. Section IV provides the findings to answer the main and sub-research questions. Section V discusses the findings and proposes an e-PB model that uses blockchain technology to address the issues identified in the current e-PB system. Finally, Section VI concludes this paper and discusses limitations, open issues, and future work for the study.

II. Related work

This section explores the existing literature that focuses on PB and its digitalization in Section II-A, and the use of blockchain technology in participatory governance processes in Section II-B, providing a comprehensive overview of current state of the art by exploring them and identifying avenues for current research.

A. Participatory Budgeting (PB) and its Digitalization

PB is a democratic process that empowers citizens and community members to engage and decide directly on the allocation of public funds [1]. As government entities, particularly municipalities, seek to improve citizen participation, PB has emerged as a powerful tool to enhance trust and citizen participation in decision making. Traditional PB methods have historically relied on in person deliberation and voting, which is effective, but suffers from several challenges, including the issue of inclusion, the difficulties of gaining community trust, and the low quality of deliberation [43].

The emergence of digital technologies has transformed PB processes by facilitating greater participation and streamlining PB processes. Many cities, including Barcelona and Helsinki, adopted DECIDIM, a digital platform for citizen participation, and customized this platform to use at the municipal level to perform PB stages [32, 44, 45]. For example, Decidim.barcelona[2] and OmaStadi[3] digital platforms have been deployed in Barcelona and Helsinki to facilitate the proposal of ideas, comment on proposals, exchange of opinions, discuss concerns of the community, provide feedback and vote on proposals in e-PB processes [32, 46].

However, these digital PB platforms also present challenges such as a lack of public discussion and deliberation, a non-user-friendly interface, digital inequalities, opportunism and distortions in the decision-making process due to the ownership of the platform that is managed by central entities [32, 46, 47]. The successful practice of PB requires the provision of essential training, skills, and mindset for managers and the necessary education for citizens to use the digital PB platform effectively and actively participate in the PB process [48]. Mattei *et al.* [2] discuss the transformative potential of PB and its alignment with citizen expectations and community needs to effectively turn citizens into active participants, thus strengthening their sense of ownership and increasing citizen participation. Similarly, Manes-Rossi *et al.* [33] highlight that democratic participation, inclusiveness, and citizen participation in final decision-making are the key drivers in PB processes.

Despite these digital advances, traditional and e-PB initiatives face persistent challenges, including insufficient transparency, resistance from the local government, and low citizen participation and trust [3, 4, 5, 6]. Furthermore, restricted monitoring of the PB process by citizens, inadequate active citizenship in decision-making processes, and the risk of manipulation in centralized e-Government systems by administrators further hinder the effectiveness of these initiatives [7, 8, 9]. Furthermore, most current e-Government systems, such as websites and digital identity management systems, are centralized and hosted on duplicate servers and databases. These systems are vulnerable due to their single point of failure from cyberattacks such as malware, denial of service, and distributed denial of service attacks [49]. In addition, centralized platforms are vulnerable to privacy and information leakage where users do not have complete control over their data, as their data is owned by technology companies and used for customized advertising [50].

These gaps highlight the need for innovative technologies, such as blockchains, that provide immutability, traceability, transparency, security, cryptography, and decentralization. These technologies achieve greater transparency, improve trust and citizen participation, eliminate intermediaries, improve the inclusiveness of service delivery, and facilitate real-time monitoring information, thus providing the required privacy and security in e-Government systems [17, 18, 20, 22, 23, 49].

B. Blockchain Applications in Participatory Processes

Blockchain technology has emerged as a transformative and potential tool to offer promising solutions to address existing issues in participatory governance processes. The core attributes of blockchain technology—traceability, transparency, immutability, security, decentralization, and disintermediation—make it particularly appropriate for handling participatory processes, including PB. Blockchains address critical vulnerabilities and risks of data manipulation in traditional and digital PB systems by creating immutable data records and enabling secure and P2P interactions without relying on third-party entities [10, 11, 12, 13, 15]. By facilitating P2P transactions and agreements, blockchains improve efficiency, privacy, and security, and reduce fraud in numerous organizations [51].

One of the most important applications of blockchain is the development of a transparent and secure e-voting system. Several studies, for instance, Taş *et al.* [39], Chafiq *et al.* [52], and Mishra *et al.* [53] demonstrated how a blockchain-based voting system/model could prevent manipulation of election results, ensure the security, privacy, and anonymity of voters, reduce fraud (i.e., double voting), and achieve transparency and integrity in the election. These blockchain-based e-voting

[2] https://www.decidim.barcelona/.
[3] https://omastadi.hel.fi/.

systems enhance security and ensure vote integrity, making voting records tamper-proof and verifiable. However, the integration of blockchains in e-Government services poses several challenges such as lack of regulation, scalability, and interoperability issues, as well as time-consuming and complicated processes in large-scale implementations [54, 55].

Beyond voting, blockchain technology facilitates promising solutions in PB processes. For example, smart contracts automate workflows such as identity verification, payment processing, and dispute resolution based on predefined conditions. These reduce manual errors, the need for trusted intermediaries, and improve efficiency in digital services provided to citizens and community members. This automation also improves accountability by ensuring that allocated public funds are spent as intended, with all transactions stored on the blockchain transparently [24, 25, 26, 27, 28].

Several studies examine the application of blockchain technology in various domains and cultural contexts, including Sweden, the United Arab Emirates, Malta, and Portugal. These countries adopted blockchain technology to reduce manual processes and operational costs, increase customer satisfaction rates, improve trust, transparency, accountability, security, efficiency, and create, issue, and verify the authenticity of educational certificates [16, 28, 56, 15].

However, the adoption of blockchain technologies in PB should ensure compliance with the GDPR, since blockchain technology benefits e-Government systems in terms of data security and transparency. To this end, implementing a private permissioned blockchain avoids cost and latency, offers more control over data, and ensures the privacy of highly sensitive information, making it more acceptable for GDPR compliance [16, 57, 58]. Moreover, implementing a hybrid blockchain is well suited and effective for e-Government, allowing citizens to access information and services using their government credentials, thus promoting transparency, accountability, data reliability and improving administrative efficiency [59, 55]. Transparent information sharing is a key factor in facilitating rapid communication and achieving efficient collaboration between stakeholders [60] in e-PB processes. In contrast, the public permissionless blockchain is limited in use by governments due to its multiple economic and technical limitations, such as built-in cryptocurrency, network latency, and the risk of unreliable contributors. Most government-implemented projects use consortium (or federated) blockchain and private-permitted blockchain for notarization, shared database, and workflow automation. For example, some real-life blockchain deployment in European countries includes land title registry / transfer (centralized / hybrid) in Georgia and Sweden, and academic certificate verification (hybrid) in Malta. Other blockchain applications include digital identity for proof of residency, electronic voting, payments for bike rental and parking (hybrid) in Switzerland, blockchain governance (decentralized) in Luxembourg, and pension system management (hybrid) and benefit management for low-income residents (centralized) in the Netherlands [61]. Therefore, most of the proposed solutions are based on consortium and private blockchains [62].

In the context of PB, numerous studies examine the application of blockchain to monitor PB projects, improve participatory processes, prevent errors associated with vote count, and improve citizen participation, trust, transparency, and inclusion [63, 64, 65, 66]. Kenetey *et al.* [63] design a consortium blockchain-based monitoring and evaluation system to establish a mechanism to monitor different budget projects, processes and transactions in the local government of Ghana, thus addressing transparency issues using cryptography techniques in budgetary processes. Similarly, Benítez-Martínez *et al.* [64] propose a blockchain-based e-participation model for the management of local governance affairs, allowing local governments to improve participatory processes using e-voting tools based on a neuronal blockchain network. The proposed model uses token-based incentives to reward participants with virtual tokens deployed through a smart contract, thereby promoting citizen participation. The study focuses on improving e-participation at the local government level using blockchain-based e-voting, but does not specifically focus on issues faced by traditional e-PB systems in Estonia, however, provides valuable insights for our study.

Similarly, Mærøe *et al.* [5] examine ways to establish and strengthen the e-democracy at the local government level through e-PB projects. Their research reveals that citizen participation in these types of projects is relatively low, stating that it is necessary to explore opportunities to improve citizen inclusion levels. We build on their work, which indicates that future research is required to address the low citizen participation rate in digital innovation that revitalizes democracy. Despite their contributions, there remains a significant gap in the literature on enhancing citizen participation in the e-PB system using blockchain and smart contracts [67].

Moreover, Muth *et al.* [65] propose a blockchain-based participation platform called BBBlockchain for urban development to address issues such as inclusiveness, trust, transparency, participation in planning processes, and co-decision-making. They opt for a permissionless blockchain platform such as Ethereum for their BBBlockchain platform, and pilot tests the project in Berlin. BBBlockchain platform integrates feedback mechanisms by integrating social networks as feedback channels to allow citizens to provide their feedback on participatory workshops or statutory planning information. In BBBlockchain, they use coins and tokens to manage voting rights and to incentivize participants in a PB process. The voting is evaluated at the end with a ZKP to validate voting tokens and ensure anonymity. Our blockchain-based conceptual e-PB model differs from the BBBlockchain platform in many ways. First, our proposed blockchain-based solution opts for a consortium/hybrid blockchain, making it more suitable and effective for government use. Our study reveals that the majority of implemented projects for e-Government applications and services either deployed consortium blockchain or private permissioned blockchain due to their compliance with GDPR. Second, the context of e-participation in terms of e-PB steps differs in different economic and cultural contexts. Therefore, the research in [65] can be used as the basis for our study by offering valuable information.

The integration of blockchains in the e-Governance domain facilitates secure and efficient public service delivery

by reducing bureaucratic inefficiencies. For example, several studies propose numerous blockchain-based model and framework, allowing governments to build trust between relevant stakeholders by facilitating robust e-Government services, and ensuring information security and privacy [68, 49].

The following table I presents an overview of blockchain-based solutions in various domains of e-Governance, particularly in the settings of e-PB and e-voting.

Consequently, it is crucial to address some stakeholders' concerns regarding privacy and loss of control in decision-making, which may stem from the increased transparency provided by blockchain technology. We propose leveraging the ZKP technique for a blockchain-based e-PB solution, which allows stakeholders to assert their identities and verify transactions without disclosure of sensitive information, thereby preserving privacy while guaranteeing the accuracy of transactions [69]. This balances transparency with protection of privacy. Moreover, integrating governance mechanisms, such as decentralized autonomous organizations, self-governing entities that operate on blockchain technology through smart contracts, ensures a balanced distribution of decision-making power and control among various stakeholders, providing a smoother transition to blockchain adoption [70]. Blockchain adoption facilitates a transparent and secure process with better quality at low cost [71]. Therefore, by integrating the strengths of blockchains and digital PB, participatory governance is transformed into a more inclusive, transparent, and secure system, thereby enhancing public trust and citizen participation in decision-making processes.

III. Preliminaries

In the rapidly evolving digital landscape, the need for efficient and transparent models for public participation is paramount. Estonia, being a pioneer in digital governance, has been at the forefront of adopting innovative solutions to improve citizen participation. This section aims to provide a comprehensive understanding of the current state of the e-PB model in Estonia and the research method used in this study to address its shortcomings. The insights derived from this section lay the foundation for the development of a blockchain-based e-PB model, which is discussed in the following sections. Section III-A presents a running case that captures the AS-IS state of deficiencies of the e-PB model in Estonia. Next, Section III-B describes the research method used in the development of a blockchain-based e-PB model that addresses the problems presented in the running case.

A. Running Case

Estonia is a country with a high level of information and communication technologies and an advanced digital infrastructure known as a digital and tech-savvy society, providing 99% government services online [72]. Estonia was the first country in the Baltic states to adopt the e-PB approach on a local scale in 2013. More than 30 municipalities in Estonia use the e-PB model for citizen participation and empowerment [73]. This makes the Estonian context an ideal case study to understand how blockchain technology can further enhance these democratic processes and address the key issues uncovered in traditional e-PB systems. The general e-PB model, as shown in Figure 1, includes the following stages [74]:

- Determination of the e-PB budget: At this stage, local public services decide on the amount of money to be provided to e-PB from the local budget. This usually involves a small fraction of the local municipal budget, ranging from 5,000 to 140,000 euros.
- Submission of ideas: Residents gather ideas on how to spend the e-PB budget through online broadcasting, such as the Web page and the traditional channel.
- Expert evaluation: The evaluation phase consists of primary activities that include assessing the economic, technical, and administrative feasibility of PB projects [32]. The initial expert analysis focuses on the technical feasibility of the project proposal and consolidates ideas about whether the budget of the proposal is realistic, followed by open thematic forums in which citizens and experts discuss the proposed ideas.
- Voting: Residents vote on selected ideas using e-tools (online), such as VOLIS (volikogu infosüsteem), an information system, and KOVTP (kohaliku omavalitsuse teenusportaal), a service portal for local governments used for e-PB in Estonia. The service has a monthly charge of 63 EUR for the former and 34 EUR for the latter. Additionally, voting can also be done on paper (offline), following the traditional voting method.
- Decision/Approval of the City Council: After the winning project is selected by the voters, local public services implement the chosen idea. This involves selecting the best decisions and presenting them for public vote in a hybrid manner (online and offline).

Generally, the evaluation phase of the PB is less participative due to being a technical step in the whole process than other phases [32].

The Estonian e-PB model is a hybrid that incorporates a mix of online and offline tools. Similarly, in the cities of Rome and Barcelona, PB is conducted in a hybrid format where the voting is entirely online; however, assistance is offered in person. In Rome, the number of votes cast for each project is visible online, while in Barcelona it is not visible online. The anonymity of the voters is ensured in the voting of both cities [32]. Several studies emphasized that the practice of PB in hybrid mode prevents digital division, allowing citizens to participate offline [31, 32]. e-PB spreads throughout Estonia and is used by more than half of the 79 local governments in the country. Implementing an e-PB can lead to the establishment of a digital democracy. One of the goals of establishing a digital democracy is to increase political and civic participation. In this regard, e-Governance cannot guarantee on its own significant increases in the level of political participation [75]. In Estonia, e-PB is implemented within the framework of the project 'PB in Local Governments' by the Estonian non-governmental organization eGovernance Academy (eGA)[4]. In the e-PB process, voting is

[4] https://ega.ee/.

TABLE I
BLOCKCHAIN-BASED SOLUTIONS IN E-GOVERNANCE DOMAIN

No.	Proposed solutions	Application domain	Outcome	Description
1.	Cybernetic model [68]	e-Government	Integrating Blockchain in e-Government services	creates trust between relevant stakeholders.
2.	Multilayered system [52]	e-voting	Transparency, immutability, and integrity	reduces electoral fraud and manipulation.
3.	E-voting system [53]	e-voting	Security	enhances security features such as unique identification keys, fingerprint authentication, and one-time passwords.
4.	Framework [49]	e-Government	Decentralization, security	prevents single point of failure by cyberattacks such as malware, denial of service, and distributed denial-of-service attacks.
5.	Model [39]	e-voting	Immutability, cryptography	prevents manipulation of election results by administrators or miners. ensures security, privacy, and anonymity of voters.
6.	Monitoring and evaluation system [63]	e-PB	Monitoring and evaluation	provides monitoring of different budget projects, processes, and transactions in Ghana's local government.
7.	e-participation model [64]	e-PB	Managing affairs	allows local government to improve participatory processes using e-voting tools by rewarding token-based incentives to participants.
8.	e-participation platform [65]	e-PB	Transparency, trust, and participation	enhances trust, transparency, inclusiveness, and participation in planning processes and co-decision-making.

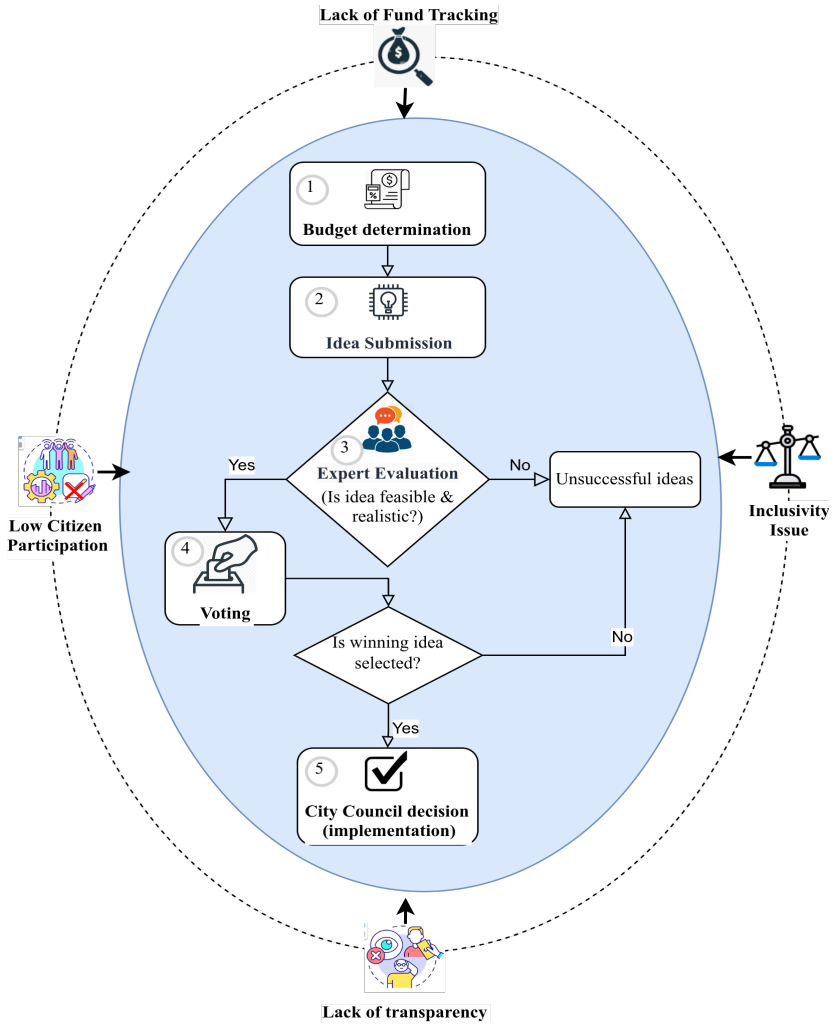

Fig. 1. The stages of e-PB in Estonia with AS-IS problem expressions.

allowed for those who have reached the age of 14, each person having the opportunity to vote for a maximum of three project ideas. Ideas can be submitted by anyone, both individuals and organizations [76]. The problems with the current e-PB model in Estonia, as illustrated in Fig. 1, are mainly caused by lower citizen participation, insufficiently inclusive e-PB processes

that exclude certain social groups, limited public oversight in fund tracking, and transparency issues. Consequently, there is a lack of an e-PB model that best fits the context and size of the city [5, 77].

B. Research Method

The research carried out in this study adheres to the exploratory case study research method in software engineering that provides research results from real-world projects [78]. Bartocci *et al.* [79] stated that most of the research focuses on single qualitative case studies of PB, which makes it difficult to generalize the findings. Therefore, we used a multiple case study to identify the deficiencies in the AS-IS state of the e-PB model in Estonia and extract data from the environment by conducting interviews with relevant stakeholders. Considering this, a holistic and multiple case study design is more appropriate because it allows examination of the entire e-PB model in Estonia by studying multiple municipalities (Rapla, Lääne-Nigula, Saue, Tallinn, and Tartu). The methodology used in this study involves semi-structured interviews and thematic analysis to identify the key challenges of PB and the benefits of integrating blockchain technology into e-PB processes. This approach is aligned with the methodologies used in similar studies in PB, which have used qualitative methods to examine the enhancement and encouragement of citizen participation [2, 33].

1) Sampling and Participants Selection Criteria: The study participants (n=16) were selected using a combination of purpose-driven sampling and snowball sampling - a non-random technique (non-probability) - to identify and recruit relevant participants [80]. Purposive sampling allows the researcher to deliberately select participants with specific qualities that are knowledgeable about or experienced with the phenomenon under study [81]. This is considered one of the most commonly used techniques in qualitative research in a broad range of scientific disciplines [82]. Snowball sampling allows researchers to identify and recruit relevant participants with knowledge in the field through referrals from initial participants [83]. Therefore, the snowball-purpose sampling technique was used to ensure a diverse and representative sample of stakeholders in the PB process.

The sampling process initially began by identifying and selecting participants purposively based on their experience and expertise who were directly involved in e-PB projects, including local government officials and IT and/or PB project managers. Subsequently, we recruit other stakeholders, such as active citizens and e-democracy experts, through the referral of these initial participants. This iterative process was repeated until thematic saturation was reached.

The selection criteria for 16 participants are as follows:

- *Local government officials:* The sample comprises seven local government public servants who hold various roles within municipalities in Estonia, including Rapla, Tartu, Tallinn, Saue and Lääne-Nigula, such as development managers, communications managers, project managers, etc. The selection criteria for these participants are their direct involvement in the administration and implementation of PB projects in their respective municipalities.
- *e-Democracy expert:* A senior e-Democracy expert from eGA is included to enrich this study by providing insight into e-PB practices in a broader context and the impact of e-participation initiatives on achieving transparency and citizen empowerment. The inclusion criteria for this participant are experience and extensive knowledge of e-democracy projects, particularly those involving PB.
- *IT and/or Project Managers:* Two participants are IT and/or project managers responsible for operating the VOLIS information system and the e-PB system. The selection criteria for these participants are their technical expertise in the execution and maintenance of the e-PB platforms and their direct involvement in the design and/or operational aspects of the e-PB systems.
- *Citizens:* Six participants are Estonian citizens who actively participated in the PB process at least once in their respective municipalities. To capture a broader range of perspectives, participants represent different demographic groups in terms of age, gender, and socioeconomic status.

2) Constructing Semi-Structured Interviews: The semi-structured interviews are designed to obtain in-depth information on the perspectives of different stakeholders on the deficiencies of the current e-PB model in Estonia and to explore the expected benefits of an e-PB model that employs blockchain technology. In software engineering case studies, semi-structured interviews are common types of interview [78]. To construct semi-structured interviews, several key steps are followed:

1) *Interview guide development:* We designed the interview guide by reviewing the existing literature on PB, electronic participation, and blockchain technology, which helps to discover relevant topics and issues for this study. Blockchain and e-democracy experts are consulted to seek their input to ensure the interview questions are appropriately formulated, and are comprehensive and relevant. In addition, we pilot-tested the interview guide with two participants to refine the questions and make necessary adjustments to ensure clarity and relevance.
2) *Interview Structure:*
   - *Introduction:* At the beginning of the interview, a brief introduction is given to each interviewee, explaining the purpose of the study, the topics to be included, and ensuring the confidentiality of each participant's response. The interview begins with a set of warming questions related to the participant's work situation.
   - *Main Topics:* The interview guide contained 23 open-ended questions grouped based on their topics to be more flexible in responses and to motivate interviewees to share their viewpoints and experiences freely. The main topics covered in the interview guide are:
     - *Tracking Allocated Funds:* Question about how interviewees currently track the allocated funds in the e-PB process.
     - *Inclusivity:* Questions on barriers to participation in the PB process for different social and demographic groups, and to what extent the current e-PB model is inclusive.

- *Transparency:* Question regarding the perception of transparency by interviewees of the current e-PB process and their suggestions for improvement.
- *Citizen Participation:* Questions aimed at understanding the factors that encourage or demotivate citizen participation in the e-PB process.
- *Challenges in the current e-PB model:* Questions on discovering the existing challenges faced by participants in the e-PB process.
- *Public Deliberation and Discussion:* Questions about the effectiveness of deliberation and discussion in the current e-PB process.
- *Expected benefits of blockchain technology:* Questions focused on potential benefits of blockchain technology.

3) *Conducting the Interviews:* The interviews are conducted in hybrid mode, and prior to the interview, the consent form is provided to each participant and explained.
   - *Communication Mode:* Interviews with two participants are conducted in person, and with the rest of the participants, the interviews are conducted via Skype video/audio calls to accommodate their preferences and ensure convenience.
   - *Duration:* The average duration per interview was approximately 41 minutes, which is enough time for extensive discussion.
   - *Recording and Transcription:* Participants gave their consent to record interviews and transcribe verbatim to ensure the precision of the captured data. The accuracy of the transcriptions is reviewed before data analysis.
   - *Ethical Consideration:* All participants gave their informed consent by digitally signing the consent form before the interviews. We coded the identities of the participants using P1, P2, . . . , P16 to protect privacy and ensure the confidentiality and anonymity of the participants.

The interview protocol has been used during the interviews and is detailed in the Appendices A, B, and C. The researchers involved in this study designed the interview protocol in collaboration. Appendix A contains an email sent to each participant requesting an interview, including information about the interviewer, the purpose of the study, and the recruitment criteria of the participant. Appendix B describes the consent form to ensure the confidentiality of each participant. Appendix C provides the complete list of interview questions, questions, and suggestions, thus concluding the interview and asking for feedback on the interview, and sharing ideas, comments, or additional information.

3) Data Collection: We conducted semi-structured interviews with 14 participants via Skype audio / video calls and with two participants in person from 8 February to 18 March 2024, totaling $\approx$ 11h, with an average duration of around 41 minutes per interview. The interviews are designed to explore the deficiencies in the current e-PB model and the expected benefits of a blockchain-based e-PB model.

The precision of qualitative data is evaluated by internal validity, external validity, and construct validity. To ensure internal validity, the data collection instrument for interviews is assessed by the co-authors to guarantee its effectiveness. For external validity, inclusion, and exclusion criteria are applied using a purposeful snowball sampling technique to target the following participants:

- Citizens who have participated in the e-PB process in Estonia.
- Local government employees responsible for administering the e-PB process in their municipalities.
- e-PB System IT and/or project managers who manage the systems to conduct e-PB projects.

To ensure construct validity, interview transcripts are sent back to key informants such as citizens, local government employees, e-democracy senior expert of the eGA, and IT and/or project managers of the e-PB system, asking them to confirm the information. Triangulation is achieved through interviews with multiple stakeholders across five Estonian municipalities, including Rapla, Tartu, Tallinn, Saue, and Lääne-Nigula. The study situates itself in a high-tech society (Estonia) with an established digital governance infrastructure. The empirical setting of the case study, involving municipalities, provides real-world insights into blockchain's potential for e-PB.

4) Data Analysis: Interview data we analyze using the RQDA, a free and open source software application designed for qualitative data analysis of textual data (that is, .txt file format) within the R environment. We use a deductive (top-down) thematic analysis method to identify, analyze, and report themes or patterns based on research questions in this primary study. Initially, we transcribe all video / audio recordings verbatim, review all transcribed interview data thoroughly by reading the text, and producing initial notes. Subsequently, we generate codes, identify, refine the themes, and finally report our findings.

IV. Results

During the data analysis process, four primary themes emerge from thematic analysis: (1) challenges/problems, (2) demotivating factors for citizen participation, (3) design elements, and (4) benefits of blockchain-based e-PB (each with its sub-themes or sub-sub-themes), as illustrated in Figure 2.

A. Challenges/Problems

This theme consists of two sub-themes: technical and non-technical challenges encountered within the e-PB system in Estonia. These challenges pose significant barriers to the successful implementation and operation of the e-PB system. The distribution of the challenges discovered during semi-structured interviews is demonstrated in Figure 3, and Table II.

The results revealed that identified challenges in the current e-PB system restrict citizens from active participation in the e-PB process, resulting in low citizen participation. Challenges such as *no fund allocation tracking* (87.5%, *n*=14), *lack of public deliberation/discussion* (87.5%, *n*=14), *low citizen participation* (81.2%, *n*=13), *transparency issue* (81.2%, *n*=13), *manipulation* (50%, *n*=8), *insufficient feedback gathering* (43.7%, *n*=7), *information barrier* (37.5%, *n*=6), *inclusivity issues* (31.2%, *n*=5), and *non-user-friendly interface* (31.2%, *n*=5)

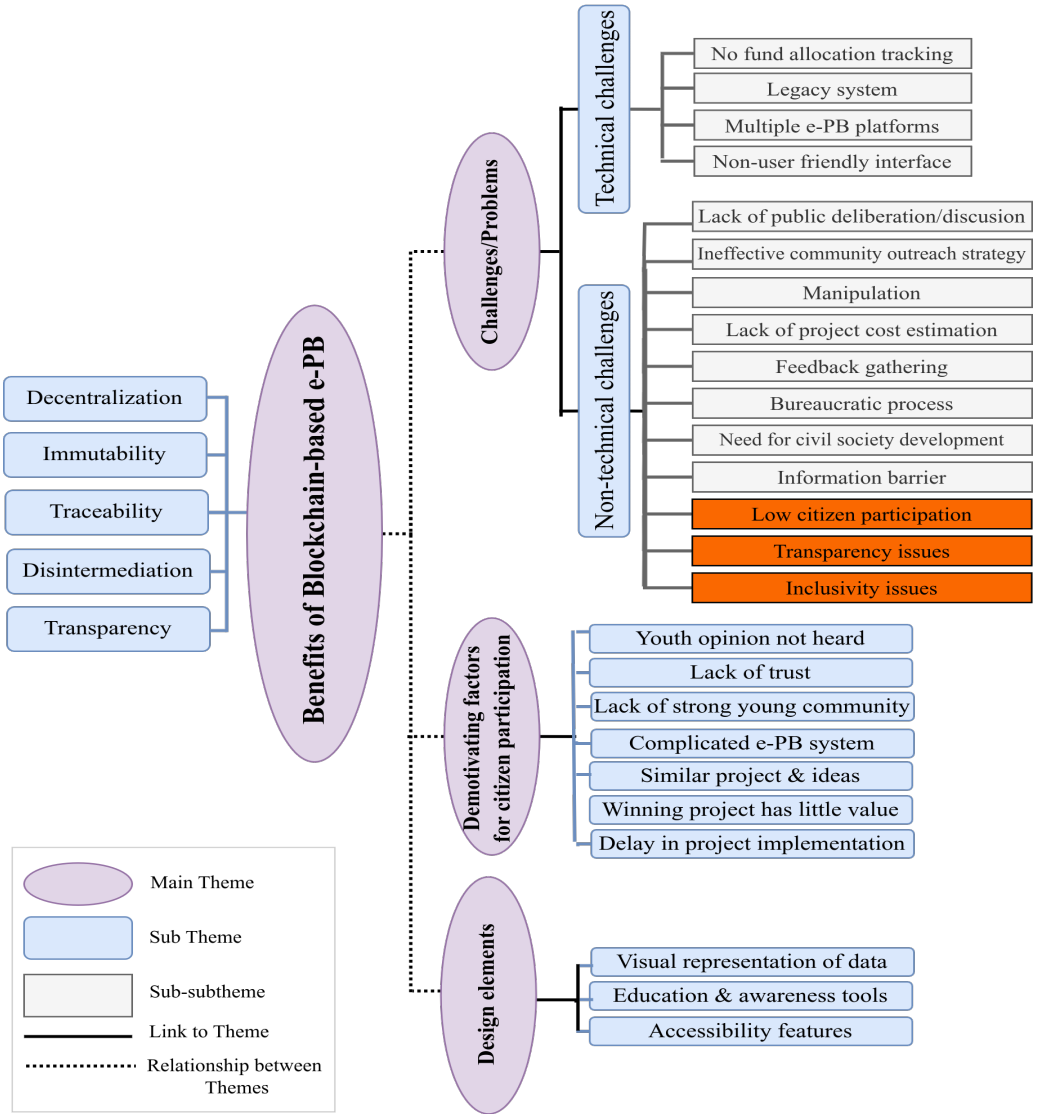

Fig. 2. Thematic map illustrating main themes, sub-themes and sub-subthemes

TABLE II
CHALLENGES DISCOVERED DURING SEMI-STRUCTURED INTERVIEWS

No.	Challenges	Participants (*n*=16)	Percentage (%)
1.	Bureaucratic process	2	12.5
2.	Manipulation	8	50
3.	Inclusivity issues	5	31.2
4.	Ineffective community outreach strategy	1	6.2
5.	Information barrier	6	37.5
6.	Lack of project cost estimation	2	12.5
7.	Lack of public deliberation/discussion	14	87.5
8.	Legacy system	2	12.5
9.	Low citizen participation	13	81.2
10.	Multiple e-PB platforms	1	6.2
11.	Need for civil society development	2	12.5
12.	No fund allocation tracking	14	87.5
13.	Insufficient feedback-gathering	7	43.7
14.	Non-user-friendly interface	5	31.2
15.	Transparency issues	13	81.2

receive the highest score considered as the major challenges. These are followed by minor challenges that receive the lowest score such as *lack of project cost estimation* (12.5%, *n*=2), *bureaucratic process* (12.5%, *n*=2), *legacy system* (12.5%, *n*=2), *ineffective community outreach strategy* (6.2%, *n*=1), *multiple e-PB platforms* (6.2%, *n*=1), and *need for civil society development* (12.5%, *n*=2), respectively.

1. **Technical challenges:** The first theme identified in the thematic map refers to technical challenges. This theme consisted of four sub-themes: (1) no fund allocation tracking, (2) legacy system, (3) existence of multiple e-PB tools/models, and (4) nonuser-friendly e-PB system.

1.1. No Fund Allocation Tracking: Participants (P11, P12, P2, P3, P4, P8 and P6) expressed concern that the funds allocated for e-PB projects are not available for real-time or step-by-step tracking to keep citizens informed. Currently, local governments disseminate this information through their local news outlets, websites, or the municipal document register, rather than through the VOLIS or e-PB system. The participants view this as a challenge that needs improvement. For example, one

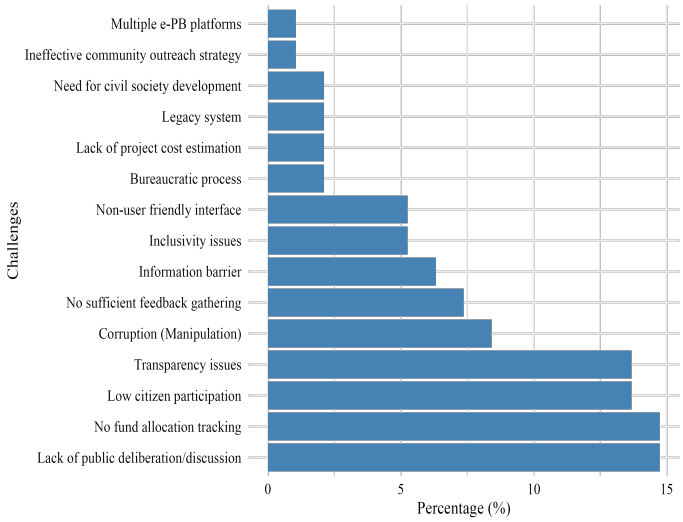

Fig. 3. Frequency and percentage of challenges uncovered in semi-structured interviews

of the participants stated that:
"There is no possibility to watch [allocated money for e-PB projects] online in real time, how much it is spending. But the local government announces that how do they spend it, or if they overspend what happens, they also explain everything usually in the news, so everyone can be aware how this money is spent."(P12)

1.2. Legacy System: The issue of the e-PB system is highlighted by diverse participants, stating that the current systems are not sufficiently upgraded, and it is limited in providing demographic information such as gender and age groups, which poses a significant problem. Moreover, some participants (P4, P6) suggested improvements to the existing system as it lacks inter-compatibility with the Estonian registers and no changes have been made to the system during the past 10 years. Therefore, participants consider this to be one of the challenges of e-PB projects. For instance, Participant (P1) expresses concern about the current e-PB system, stating:
"Our systems, which are in use now, are not sufficiently upgraded. This is in fact a problem."(P1)

1.3. Existence of Multiple e-PB tools/models: Multiple e-PB systems are employed by various municipalities throughout Estonia to facilitate e-PB processes. In the municipality of Tallinn, e-PB processes are facilitated through the use of two distinct systems: The first system[5] is used to gather ideas and the second system[6] is used to conduct e-PB voting, compared to the VOLIS or KOVTP systems. In contrast, most other municipalities predominantly utilize the VOLIS information system for their e-PB processes, which is not free of its own set of challenges. In this regard, the participant (P9) reveals that using several e-PB systems instead of one system creates challenges. These challenges increase the amount of manual work, which presents a challenge that could create opportunities for manipulation.
"Tallinn uses two different systems. For those ideas to reach our system, someone from the government office needs to manually enter them into our system. They can also upload them from a comma-separated values file [A plain text file containing tabular data separated by commas], but the data does not transfer automatically... and when it gets to the payments part, then it is also a manual work in another system. I think it was last year when the government officer started entering those ideas into the system. For one project or for one idea, they completely changed the title..." (P9)

1.4. e-PB system not user-friendly: Participants (P4, P6, P7, P11, P16) declare that the current e-PB systems are not user-friendly and are particularly unsuitable for younger users to use on mobile devices. This signifies a challenge that leads to reduced citizen participation, as it fosters a sense of dissatisfaction and discomfort, particularly deterring the participation of youngsters. In addition, the participants (P6, P7, P16) believe that an ideal system should be visually appealing, easy to access, and user-friendly. For example, the participant (P6, P16) noted:
"The problem is that this current system [VOLIS] is not user-friendly, and this side needs to be improved. In addition, there is a discussion channel in the e-PB system that citizens do not use due to lack of user-friendliness." (P6, P16)

2. **Non-technical challenges:** This study identified the following 11 non-technical challenges that significantly impact the success and effectiveness of the system:

2.1. Lack of public deliberation/discussion: The participants (P1, P7, P8, P9, P10, P11, P12, P13, P14, P15) express their shared concern about the lack of public discussion in the decision-making process. They perceive a gap between idea submission and voting, which they believe hinders inclusivity and transparency, leading to a sense of detachment among citizens. The current system, in which an expert commission makes initial decisions, is seen as opaque and not inclusive. Participants suggest that democracy should extend beyond voting to include channels for citizens to introduce and discuss their ideas. They also highlight the need for a neutral, official page for discussions, moderated to ensure productive dialogue. However, they note that current discussions are limited and often dominated by specific groups. They suggest that public deliberation should occur before voting, allowing community members to collectively discuss and address problems. They also highlight the need for more detailed project descriptions, suggesting that ideas should be thoroughly refined through public

[5] https://www.tallinn.ee/en/participatorybudget.
[6] https://taotlen.tallinn.ee/.

deliberation after submission. Therefore, participants find that the lack of public debate is a critical challenge in the e-PB process. In addition, a participant (P11) proposes features like a rating option to give stars from one to five in the e-PB system during the idea collection phase and a channel for open discussions about the projects. For example, the participant (P15) stated that:

"We are lacking one step between submitting ideas and voting, and this is public discussion to get closer to the citizens and discuss P2P. Public discussion would help make the process more inclusive and transparent so that people have the idea and feel that they are actually a part of the process. Right now, the expert committee is making the first decisions... [and it] is not visible or transparent enough in terms of how these decisions are made." (P15)

2.2. Ineffective community outreach strategy: The main challenge of e-PB is to engage and inform the public, especially young people, who often feel disconnected from the process and are difficult to reach through traditional media. According to (P1, P6, P9, P13), there is a need for better communication strategies, including the use of fancy platforms, not merely text and messages, to speak in the language of the younger generation and keep people interested and involved. Information sharing should also be improved. Therefore, participants perceived that the lack of an effective community outreach strategy is considered one of the challenges in the e-PB system in Estonia. For example, the participant (P6) stated that:

"Engaging young people is, of course, a challenge for us because young people are not very active in similar processes. They don't find this process interesting and don't feel connected to it. They do not use traditional newspapers or listen to the radio. Our task is to get them where they are..." (P6)

2.3. Manipulation: Blockchain networks use consensus protocols to validate transactions. In the context of e-PB, these protocols can be used to validate votes. This ensures that only legitimate votes are counted, which in turn helps to avoid e-vote manipulation. The participants highlighted the external influence and manipulation of paper votes in the e-PB project. However, they believe that these are considered a challenge due to the minimal likelihood of vote manipulation and external influence. In this regard, the participant (P5) noted that:

"...the ideas and votes submitted through the papers are very minor percentage. There is a little room to actually manipulate something." (P5)

2.4. Lack of project cost estimation: Participants believed that without project cost estimation, some ideas can be difficult to implement. As a result, these ideas are often postponed or not implemented at all, leading to lower citizen participation. For example, the participant (P3) stated that:

"The biggest challenge is that while people...present ideas, but they cannot imagine how much [these ideas] cost." (P3)

2.5. Feedback gathering: The participants (P3, P6, P7, P8, P12, P14) identified a significant issue in the current system: the absence of an official tool or dedicated mechanism to provide feedback on the process. They noted that there are no specific tools or Web pages dedicated to providing feedback on e-PB projects. Community members or citizens currently have the option to express their opinions via the local government's Facebook page, email, or phone calls. A municipal public servant is available for consultation and is open to receiving feedback directly through his or her personal contacts, email, or Facebook messages. However, it remains unclear whether the city council is monitoring comments made on Facebook. The participants expressed that the establishment of a dedicated feedback mechanism would facilitate the collection of more comprehensive feedback from the community. They underscored the critical role of feedback in continuous improvement and in meeting the needs of the community. They emphasized that a well-designed feedback mechanism not only encourages the community to provide more feedback, but also facilitates better communication, enables more informed decision-making, and ensures that the selected projects are beneficial to the community as a whole. Therefore, having a robust and accessible feedback mechanism in place for community projects is of paramount importance. For example, the participant (P8) noted that:

"There is not enough possibilities for citizens to provide feedback about the project, that is one thing I definitely had a problem with..." (P8)

2.6. Bureaucratic process: Participants (P2, P5, P15) noted that there are some bureaucratic processes in the background. These processes, which include handling large budgets, are designed to ensure that everything is transparent to the public. However, these bureaucratic procedures do not pose a challenge for e-PB projects. In this regard, the participant (P5) highlights that:

"...if you want to be responsible, you have to provide evidence of how the money is spent. However, providing the evidence itself increases bureaucracy." (P5)

2.7. Need for civil society development: The participant (P1) highlights the need for a strong civil society in the region to support good ideas from citizens. A civil society refers to organizations, groups, and movements that are independent of the government and actively participate in public life. These groups can help bring citizens' ideas and needs into the e-PB process. She stated that:

"...there should be some good development of the civil society in this region to get these ideas and the needs of the locals in this process of e-PB. Voting is quite smaller yet." (P1)

2.8. Information barrier: The participants (P1, P5, P7, P8, P9) highlight a significant barrier to effective citizen participation in e-PB: the lack of accessible and trans-

parent information. The participant (P7) identifies an information gap that excludes certain social groups from participating, mainly due to her inability to access relevant information. This issue is further exacerbated by technical glitches, such as non-functional links, which hinder the participant's ability to track the progress and results of their project. The participant (P9) points out the absence of post-voting updates, which leaves them uninformed about the completion status of the projects. This lack of continuous communication and transparency contributes to the low participation of citizens in e-PB. The insights of the participants underscore the need for improved information dissemination and technical robustness in e-PB systems to foster greater civic engagement. Therefore, participant (P5) stated that:

"It is an issue for some social groups to be excluded from information flows. And they basically just do not receive the right information and opportunities to participate." (P5)

2.9. Low citizen participation: The allocation of a minimal budget for e-PB, coupled with the lack of motivation among young people to participate in the e-PB, are identified as significant barriers to greater acceptance of the e-PB process. The participants noted that the current funds allocated for the e-PB project are insufficient and believed that this is the main challenge. The participant (P5) states that:

"The amount of ideas submitted is very impressive, and...in that sense, people are participating. But when it comes to voting, for some reason, people do not want to vote." (P5)

2.10. Transparency issue: Participants (P1, P5, P13, P14) raised their concerns about the lack of transparency and communication in the internal decision-making process of the e-PB system, particularly during the ideas selection and implementation stages. These issues are considered a major challenge in the e-PB process. The participant (P14) states that:

"There's a lack of communication [and transparency] with respect to the internal decision-making process, [this] could be more transparent, especially when evaluating the considerations behind why some ideas are not chosen. During the implementation stage, it would be helpful to know why certain ideas are sorted or why they are implemented in a particular way." (P14)

2.11. Inclusivity issue: The participants (P7, P8) expressed their concerns about the lack of inclusion in e-PB projects. They feel that certain groups, such as people of color, low-income individuals, women, the LGBTQ+ community, and the elderly, are not adequately represented. They suggested that more diverse projects could attract a wider range of voters. However, some participants feel excluded from these community involvement projects, despite their attempts to contribute. Therefore, they believed this as a challenge to be addressed. For example, the participant (P7) noted that:

"...this [PB project] supposed to be a community participation project. But it does not involve me at all. In addition to that, I have been involved in a workshop to put forth my idea." (P7)

B. Demotivating factors for participation

Participation in e-PB projects is often influenced by a variety of factors. These factors underscore the challenges of effectively engaging citizens in e-PB processes, ranging from distrust in the system to perceptions of inefficiency and lack of impact. These factors can discourage individuals from participating in the e-PB process. The following are seven demotivating factors for citizen participation identified in this study:

1. Youths' opinion not heard: Participants (P8, P11, P14) perceive that young people, particularly those aged 20 or under, often feel their voices are not heard in decision-making processes that can lead to dissatisfaction, especially when their proposals are not successful. In this regard, the participant (P8) stated that:

   "...this depends on the social group to which you belong. All my friends vote, so obviously I vote too, and we discuss these issues. But there is definitely a feeling that your voices are not heard and that you, as one person, cannot really change anything." (P8)

2. Lack of trust: Participants (P10, P15) express that their opinions are not valued and their ideas are not implemented, raising concerns about trust within the e-PB system. This has led to a decrease in participation despite an increase in the number of ideas submitted each year. For example, the participant (P15) stated that:

   "We definitely see one problem where the objects (project people voted for) are not implemented, like from the first year. So, trust is decreasing." (P15)

   In addition, another participant believed that:

   "They [the municipalities] do what they want anyway." (P10)

3. Lack of strong youth community: Participants (P12, P13) believe that strong youth communities in municipalities lead to greater youth participation because young people feel that their ideas can be realized. Participants (P12, P13) identified the lack of such communities as a challenge, as young people are unaware of the e-PB process. In contrast, the participant (P2) expresses that the municipality of Lääne-Nigula has its own youth parliament to keep young people informed. The participant (P12) declared that:

   "...if the municipalities have a very strong youth community, with youth centers and various options to include young people, then these young people are likely to participate in these [e-PB] processes." (P12)

4. Complicated e-PB voting system: Participants (P11, P12) highlighted the complexity of the e-PB system as a significant issue. They emphasized that the e-PB system should be simple, as users prefer ease of use. For example, the participant (P12) noted that:

"... the [e-PB] voting system [VOLIS] is too complicated. So, the easier, the better." (P12)

5. Similar project & ideas: The participants (P6, P8, P9, P12, P14) believed that the lack of innovative ideas, as well as the repetition of similar ideas or projects, is one of the key obstacles to increasing citizen participation. In this regard, the participant (P9) stated:
   "From year to year, all the projects are the same. The ideas are the same. There are not many new innovative ideas." (P9)
6. Winning projects have little value: The participants (P7, P8, P12, P15) perceive a lack of value and relevance in the e-PB projects in the community as the main problem. The participants express frustration over the small scale and limited budget allocated for e-PB projects. They argue that projects often turn out to be pointless or uninteresting, lacking the potential to bring significant change or benefit to the community. Furthermore, the decision-making process is not transparent and does not reflect the preferences of the majority. Still, a participant (P4) from the Saue municipality notes that their local budget for e-PB is significantly higher compared to neighboring municipalities. Therefore, participants (P7, P8, P12, P15) indicated the importance of aligning projects with citizens' interests and values, ensuring transparency, and making participation meaningful and valuable. For example, the participant (P12) suggested that:
   "... the project size and the money is so small. So, it is like something 20,000 EUR, maybe, 40,000, or 50,000. Still, it is a very small amount of money, and... my ideas are much bigger, for example, to make some kind of change." (P12) Furthermore, the participant (P7) believes that the money could be better used to involve more people and make decisions that meet the needs of the community. Therefore, the participant stated that:
   "... it is not worth using 100,000 euros to... put one tap for drinking water. That is not involving; it is just the devaluation of all these projects" (P7)
7. Delay in project implementation: The main issue highlighted by the participant (P9) is the lack of implementation of winning projects. The participant expresses disappointment that a project they voted for four years ago, despite winning, has not been implemented. This experience has led to uncertainty about the status of other projects they have voted for and has undermined their confidence in the voting process. The participant notes that:
   "... some [e-PB] projects, even those that have won, are not yet implemented. It is disappointing. I am uncertain about the status of other projects that I have also voted for. It does not give me much confidence to vote the next time." (P9)

C. Design elements

The design of a system has a significant impact on its usability and effectiveness. The following are some of the design elements that enhance the user experience and functionality of a system.

1. Visual representation of data: The participants (P3, P6) emphasized the importance of visual representation and interactivity in data presentation, highlighting that people appreciate interactive elements, such as real-time voting results. For example, the participant (P3) stated that:
   "... if you vote then you see immediately how many votes are given for one or another project, it is changing in real time, so these visualizations and interactivity are very important." (P3)
2. Education & awareness tools: The participants (P1, P6) believe that educational and awareness tools play a crucial role in e-PB. They stated that the use of these tools not only improves citizens' understanding of the city budget, but also promotes a collaborative approach between the government and citizens. The participant (P6) emphasized that:
   "Education and awareness tools are very important...to improve understanding of the city budget."(P6)

3. Accessibility features: These features in the e-Governance and e-PB systems are essential to foster a democratic, transparent, and inclusive society. They ensure that all citizens, regardless of their abilities or location, can participate in government processes and decisions. The participants have different perspectives. The participant (P9) states that the e-PB system of Tallinn, rather than the VOLIS system, incorporates accessibility features, while another participant (P6) indicates that their e-PB system (i.e. VOLIS) lacks this universal design element. Therefore, the absence of this feature is considered a significant challenge, as it hinders broader citizen participation. The participant (P6) stated that:
   "Accessibility features are very important. But our VOLIS is not very accessible at the moment..."(P6)

D. Expected benefits of Blockchain-based e-PB system

The application of blockchain technology in e-PB systems provides numerous advantages, which are attributed to the intrinsic properties of blockchain. The following are some expected benefits of a blockchain-based e-PB system identified in this study:

1. Decentralization: This feature is crucial in an e-PB system based on blockchain, as it ensures that the decision-making process is not controlled by a single authority, thus promoting transparency and fairness. The participants' perspectives on the decentralization feature of blockchain in the context of e-PB vary significantly, and the participants' viewpoints reflect a diverse range of perspectives, spanning from optimism regarding decentralization's potential benefits to skepticism about its applicability in certain contexts. Participants (P1, P5, P8, P12) believe that decentralization would enhance their interest and motivation to participate in the e-PB processes. They highlight the importance and benefits of decentralization for e-PB, specifically feedback and information exchange, distribution of power and resources in e-PB processes, and P2P interaction and

communication with other participants. Decentralization is seen as facilitating discussions on a larger scale and enabling the contribution of ideas for organizing things more broadly, and believing that it would make their vote and voice feel more significant and impactful. Yet, the participant (P14) adopts a more cautious stance, expressing uncertainty about the practicality of decentralization in the physical realm of e-PB, while acknowledging its potential efficacy in online transactions. The participant (P1) noted that:
"Basically, decentralization might be good for e-PB, as it simply provides more resources and power to local governments."(P1)

2. Immutability: The data recorded on the blockchain cannot be tampered with or altered by anyone, not even the government itself. Therefore, stored data cannot be changed and is safe from manipulation. Participants (P1, P8, P9, P11, P12, P15, P16) believe that the immutability feature of blockchain could be beneficial in voting systems, providing absolute guarantees that no one can modify the data. This would increase the security of the system, thus motivating citizens to participate. This ensures that the system is safe from hacking or tampering, even by officials, which can reassure voters that their votes are secure. In addition, they emphasized that this feature increases transparency, increases the trust of citizens in the municipality and the e-PB system, improves the performance of the local authority, and improves the public reputation of the authority. The participant (P9) suggests that the integration of smart contract and blockchain technology into the e-PB system could protect information, reduce manual work, and potentially automate certain processes. Still, the participant (P11) expresses concern about the need for voters to have the ability to alter their votes on the blockchain at a later time. This is to prevent coercion or manipulation if the voter is compelled to vote in a specific manner and is uncertain whether the blockchain can meet these requirements. For example, the participant (P8) pointed out that:
"If the system is safe and no one can hack or change it, even the officials, then I feel safe... knowing that the system is designed and operates in a way that prevents them from tampering with it reassures me that my votes are safe."(P8)

3. Traceability: Blockchain traceability refers to the ability to track and verify the origin, history, and status of transactions and data or products in a distributed ledger. This can benefit the local government by enabling efficient and accurate tracking of budget allocation and spending, as well as reducing the risks of fraud and corruption. Participants (P1, P7, P9, P11, P12, P15, P16) highlight the importance of traceability in systems, particularly in voting and e-PB processes that increase citizen participation by motivating people. They believe that the traceability feature of a system can ensure transparency and accountability, which can build trust towards the system, the municipality, or the government. In addition, they emphasize that it is important to trace all changes, knowing who made them and when. Therefore, traceability is crucial in e-PB, where local residents are at the center of all processes. In this regard, the participant (P11) said:
"The traceability feature will be suitable to ensure transparency and accountability. If a person can truly track that and see the steps in the system, of course, it will build trust with the system."(P11)

4. Disintermediation: Blockchain systems operate without the need for intermediaries, such as banks, agencies, or platforms. This can benefit the local government by reducing the costs and complexity of the budgeting process, as well as increasing the speed and efficiency of transactions and data exchange. The participant (P8) emphasizes the benefits of disintermediation, highlighting that removing intermediaries simplifies processes, reduces the risk of errors or manipulation, and increases trust in the system, thus motivating citizens to participate. On the other hand, the participant (P9) acknowledges the need for some level of intermediation to ensure idea quality and adherence to rules, but agrees that disintermediation could enhance transparency. This is in line with the research in [23], which reveals that full disintermediation through pure P2P blockchain transactions is implausible. The participant believes that implementing such a system would require significant changes on the government side. Therefore, the participant sees the potential to eliminate the middleman in the process but not necessarily in the selection of ideas. The participant (P11) discusses the potential challenges of implementing blockchain technology for e-PB and suggests that using a blockchain-based e-PB system in all municipalities makes sense instead of implementing separate blockchain technology in a single municipality. Finally, participants (P15, P16) link disintermediation with increased trust in the government and suggest that it could lead to positive social benefits. For example, the participant (P8) suggests that:
"When you remove the intermediary... there is less chance of misinterpretation and less risk that something goes wrong. This allows for free exchange of ideas and thoughts. When there is an intermediary,... [it] makes the process longer and a bit more complicated. So, when the process is simplified and the need for an intermediary is eliminated, obviously, the motivation to participate also increases because it is so clear to you."(P8)

5. Transparency: The transparency feature of blockchain provides visibility of all transactions to all participants in the network, ensuring complete transparency. Participants (P1, P8, P11, P12, P15, P16) view the transparency feature of blockchain positively as a means to enhance trust, visibility, and accountability in governance processes. The participant (P1) emphasizes

the importance of visibility and transparency in the implementation phase of e-PB processes, suggesting that the information should be visible. Similarly, the participant (P8) agrees that the blockchain can enhance information visibility, making it easier to understand how funds are allocated and used. They argue that increased transparency would make citizens feel safer and more involved in the process. Consequently, participants (P12, P15) believe that visibility of all transactions can positively impact the building of trust between participants in the network, as well as increase trust with the municipality or government, providing transparency and accountability. For example, the participant (P12) stated that:

"I think this visibility of all transactions by participants in the network... is good for both sides [citizens and government]. Because there is always this question of where did the money go? And if you have this list of transactions, you can look at it here. So it is always like building a trust so that we have nothing to hide."(P12)

The factors that influence three main issues, such as citizen participation, inclusion, and transparency, are indicated in Table III.

TABLE III
INFLUENTIAL FACTORS

No.	Main issues	Influential factors
1.	Citizen participation	Sufficient project funds, upgraded & user-friendly e-PB system, better communication strategies such as using fancy platforms not only text and messages, project cost estimation, the need for civil society development, information accessibility, post-voting updates, innovative and interesting project ideas, avoiding delays in implementation of winning projects, visualized data using graphs & charts, and accessibility features.
2.	Inclusivity	Adequate representation of people of color, low-income residents, women, LGBTQ+, and senior citizens.
3.	Transparency	Public discussion, and clear communication in the internal decision-making process during the idea selection and implementation stages.

Therefore, we propose a blockchain-based conceptual e-PB model that integrates key features of blockchain, such as immutability, traceability, transparency, and disintermediation, to address the issues discovered in the current e-PB system. The results revealed that integrating decentralization feature of blockchain encourages citizens to participate actively in e-PB process without relying on a central authority, provide feedback and comments on proposals and discuss with themselves, thereby achieving transparency through P2P interaction and communication. This characteristic is depicted in Figure 4 by a P2P network structure to allow citizens to discuss the feasibility of ideas, the scope of the project, and estimate the cost of the project, thus eliminating the need for intermediaries and facilitating direct interaction and effective two-way communication between citizens and the e-PB system.

The results highlighted the importance of the immutability feature of blockchain, where the data stored on blockchain are safe from manipulation and modification and cannot be altered by anyone. This feature is suitable in the voting phase of the e-PB that creates trust between citizens, the municipality, and the e-PB system as well as assures that the citizens' votes are safe from manipulation by officials. Therefore, integrating this feature encourages participation of citizens, improves transparency, and promotes the performance of local government. Moreover, the integration of blockchain and its smart contract into the current e-PB system protect information and automate certain processes by minimizing manual work. This aspect of immutability is indicated in Figure 4 through secure and tamper-proof interconnected blocks in the blockchain, where each block contains the mathematical hash value of the previous block, making it impossible to modify previous transactions without affecting entire chains.

The results demonstrated that the traceability feature of the blockchain allows citizens to track the flow of funds, its origin and history, and the status of project progress, thereby ensuring transparency and accountability and building trust with the system. Our conceptual model in Figure 4 clarifies this feature through the detailed transaction records existing on the blockchain. The results highlighted that the disintermediation feature allows citizens to freely exchange ideas between themselves without reliance on trusted third parties, making the process simple and shorter, and ensuring the quality of the ideas, thus reducing the risk of manipulation. The disintermediation process in our conceptual model is demonstrated by directly connecting citizens with the e-PB system in Figure 4. Therefore, the administrative burden and the risk of manipulation are reduced, as pointed out in our findings.

The findings indicated that the transparency feature of the blockchain enables citizens to see all transactions on the network and understand how the allocated funds are used. This visibility of transactions promotes greater transparency and accountability in the implementation phase of e-PB processes, thus increasing citizen participation and creating trust between citizens and the government. Our conceptual model in Figure 4 illustrated the transparency feature by enabling citizens with access to the system to see and audit all transactions on the network.

V. DISCUSSION

This section provides the key findings of this study in the context of the existing literature and frameworks on PB, e-participation, and blockchain technology. We critically analyze to explore how our results align with or diverge from previous studies, thus comparing our findings with recent studies to present a detailed analysis.

Our findings are grounded in the Estonian e-PB system, and examining how these findings can be generalized to other cultural settings is crucial. Therefore, to better understand the applicability and limitations of the proposed blockchain-based conceptual model, we explore the similarities and differences of our findings across various other cultural contexts as follows:

- **Italy:** Our findings corroborate prior research by Mattei *et al.*, who observed that in Carloforte (Sardinia), the lack of

citizen participation is a more common challenge in the evaluation phase, which requires technical expertise often inaccessible among citizens [2]. Similarly, our findings indicate that Estonian citizens are not involved in the expert evaluation phase, where expert evaluation committee members assess the feasibility of ideas. Therefore, this highlights a common challenge in the PB system. The findings of this study identified the lack of public deliberation and discussion in the PB process in Estonia, which aligns with Santolamazza *et al.*, who demonstrated that the PB platform adopted in Rome lacks important features such as dedicated forums, or digital spaces for the exchange of ideas in the PB process to enable citizens to engage either by themselves or the administration in the deliberation and discussion. The dedicated DTs in Rome's PB platform support only 'like' buttons, and do not serve the purpose of deliberation and discussions [31]. Our findings extend this by emphasizing the need for creating a dedicated official page for deliberation and discussion in a P2P and decentralized way to ensure productive two-way dialogue and enhance inclusivity and transparency. The findings of this study also highlighted the transparency concerns during the evaluation phase of the PB system, particularly during the idea selection and implementation stages, where citizens are unaware of how decisions are made. This is consistent with the study in [31], which revealed that DTs facilitate information sharing for citizens, while they failed to increase citizen participation in the evaluation and implementation phases of PB projects. Our study suggests that blockchain technology has the feasibility to address this gap by providing an immutable and traceable record of decisions, ensuring transparency and accountability at each stage of the PB process.

- **Spain:** Manes-Rossi *et al.* observed a lack of coordination between the administration and citizens in Zaragoza, Spain, due to the limited role of the participatory committees [33]. Similarly, Mattei *et al.* highlighted that the use of the digital democracy platform (i.e., Decidim.Barcelona) in Barcelona, significantly enhanced citizen participation by achieving effective two-way communication, facilitating spaces for discussion, and allowing citizens to provide feedback related to each phase of the PB process [32]. In contrast, our study revealed that in Estonia, the use of multiple systems by various municipalities during e-PB processes increases manual workload, and creates opportunities for manipulation and external influence. Unlike the dedicated feedback mechanisms that exist in Barcelona's digital democracy platform, Estonia lacks a robust and accessible feedback channel integrated with the current e-PB system to collect and process citizens' feedback. While, the current feedback mechanism in the Estonian e-PB system relies on indirect methods, such as Facebook, email, or phone calls, which may not be effective in gathering complete feedback. Therefore, the establishment of a robust and accessible feedback mechanism could facilitate better communication, enable more informed decision-making, and ensure that the selected projects are beneficial to the community as a whole.
- **Russia [Yuzhno-Primorskiy Municipality of St. Petersburg]:** Golubeva *et al.* [34] demonstrated that encouraging and motivating citizens has the greatest, statistically significant influence on citizens' involvement in PB, while successful implementation of e-PB projects enhances citizens' trust in authorities. Consistent with this, our study demonstrated that the current e-PB systems in Estonia are not user-friendly, especially on mobile devices where users prefer ease of use and simplicity. It is also not sufficiently upgraded, and lack intercompatibility with the Estonian registers. Moreover, there is a lack of statistical visualization of demographic data such as age, gender, proportion of male and female using graphs or other visual elements, and dedicated feedback provision mechanism in the e-PB system, which results in low citizen participation. To address these shortcomings, this study proposes several improvements that extend the recommendations of Golubeva *et al.* on the development of a dedicated mobile application for e-PB:
  - Traceability feature: integrating a real-time tracking feature into the e-PB system to achieve greater transparency and allow citizens to monitor how the allocated funds are being spent.
  - System upgrade: upgrading the system and ensuring its compatibility with the Estonian registers to enhance its functionality and usability.
  - User-friendly graphical user interface: creating a user-friendly mobile app for e-PB systems to motivate participants, particularly young citizens, who rely heavily on mobile devices, thereby providing users with the most convenient environment to work with the application.
  - Communication channel: This allows the citizens to communicate and exchange opinions with each other, contributing to the complete implementation of PB practice.
  - Mechanism for feedback provision: Providing a means for feedback provision by citizens to the local authorities related to project implementation, project status, and project quality would have a tangible impact on influencing citizens' motivation to participate in the e-PB process.
  - Statistical information: visualizing demographic data of participants (e.g., age, gender, participation proportions) using graphical elements provides greater transparency and highlights the collective efforts. This approach fosters inclusivity and improves the understanding of citizen engagement across different groups in the PB process.
- **Serbia:** Milosavljević *et al.* identified the key challenges of e-PB in Serbia as lack of interest, low citizen participation in the project selection process, and the small amount of funds allocated for the implementation of PB projects [35]. Consistent with these findings, our study highlighted the allocation of a small amount of budget

to e-PB and the lack of motivation among young people to participate in PB as the main challenges. Similarly, Mærøe *et al.* indicated that an increase in the amount of funds in e-PB projects causes a future high participation rate, thus, allocating a higher fund in e-PB projects positively correlates with enhanced citizen participation [5]. Furthermore, our findings extend this by identifying unsuccessful ideas as a key factor discouraging future participation and diminishing interest in e-PB initiatives.

- **Poland:** Nemec *et al.* [36] highlighted several challenges in the Polish PB processes, including lack of reporting on the implementation of PB, poor communication between administrative offices and residents, insufficient funds, and low citizen participation. Our findings align with these findings and further identify another challenge, which is the lack of effective community outreach strategies for youth communities in municipalities or platforms to keep young people informed and involved in the PB process. Therefore, the study suggests a need for municipalities to invest in youth centers, or youth communities and platforms that can engage young people and make them feel included in these processes.
- **Croatia:** Džinić *et al.* [37] identified the lack of trust between citizens and local authorities in Croatia as a barrier to citizen participation, where citizens believe that their opinions are ignored. This confirms our study's finding that low citizen participation is a significant barrier to greater acceptance of e-PB. Younger citizens expressed concerns that their voices are not heard in decision-making processes, their opinions are neglected, and their ideas are not implemented. In addition, they distrust the PB system, resulting in lower participation.
- **Belarus:** Krivorotko and Sokol highlighted that decentralization in the PB facilitates cooperation between citizens and local authorities, as well as the development of projects and activities that create strong connections between communities and citizens, thus building trust and supporting local democracy [38]. Our findings align with this, highlighting that decentralization could increase citizens' interest and motivation to participate in e-PB processes. Specifically, decentralization supports feedback and information exchange, distribution of power and resources in e-PB processes, P2P interaction and communication, and online transactions. Similarly, our study confirmed the findings of Bartocci *et al.* who emphasized that the effectiveness of PB is constrained by the presence of centralized and non-democratic authorities and political elites and technocrats [79]. This further underscores the importance of decentralization in developing an inclusive and participatory e-PB system to empower citizens and improve democratic engagement.

The delay or lack of implementation of winning projects is highlighted as the main issue, eroding trust in the voting mechanism and casting doubts on the progress of other initiatives. Our findings align with the work of Sedmihradská *et al.* [84], who showed that the prolonged delay between project submission and implementation creates unnecessary distrust toward the municipality or its authorities. Therefore, it underscores the need for faster and more open execution of successful projects to maintain trust and transparency.

The lack of real-time fund allocation tracking is a significant issue that limits the transparency of e-PB projects, potentially affecting the trust of citizens in the system. This aligns closely with the findings of Rabe *et al.*, who emphasized that transparency in such systems can be achieved through accessibility and comprehensiveness of information, increasing accountability of stakeholders, and managing conflicts. Accessibility depends on the traceability and immutability features of the blockchain, enabled by the consensus mechanism that prevents data manipulation, making transactions impossible to reverse or remove from the blockchain by users, thus ensuring data reliability and integrity. Tracing historical records back through timestamping and proof of content origin is achieved by the tracability feature of blockchains [85].

The lack of project cost estimation is highlighted as a challenge that leads to the postponement or non-implementation of some ideas, resulting in lower citizen participation. Therefore, providing a project cost estimate through public discussion could help in the effective implementation of ideas and increase citizen participation. In the background, there are bureaucratic processes to handle or manage the documentation of millions of euros. However, these processes do not pose a challenge for e-PB projects. Inefficient use of public funds for community projects is identified as a main issue. This highlights the need for a more efficient and effective use of funds to involve more people and make decisions that meet community needs.

This study found that the issue of inclusivity is a concern in e-PB projects, where certain groups feel underrepresented. This aligns with the findings of Bartocci *et al.*, who found that inclusion issues persist even in developed nations [79]. Furthermore, inclusiveness can be achieved through platform usability, visualized content, mobile and browser-based decentralized applications (DApps), and information accessibility and openness to motivate all stakeholders, particularly citizens, to contribute by giving a sense of community [85].

The study also highlighted the need for a strong civil society to support the promotion of ideas and needs of local people in the e-PB process. This finding reflects the finding in [79] that states that civil organizations play a positive and vital role in the production of PB ideas and the expansion of citizen participation. Citizen empowerment, civil society activism, and social justice are considered core values of participation, thus creating a sense of community.

The finding of this study indicated that the lack of accessible and transparent information is a significant barrier to effective citizen participation in e-PB. This information gap excludes certain social groups from participating and is further exacerbated by technical glitches and the absence of post-voting updates. This finding corresponds with the study in [31] indicating that citizen participation does not occur in the post-voting stages in e-PB due to deficiencies such as regulation and insufficient updating of information.

The findings of this study indicated that the lack of innovative ideas, the limited budget allocated for e-PB projects,

and the lack of value and relevance of e-PB projects in the community are identified as key obstacles to increasing citizen participation, thus not creating significant changes or addressing community priorities. This conforms to the findings of Bartocci *et al.* [79] who found that greater citizen participation in the PB process is facilitated by expanding PB funding and broadening eligibility criteria, better addressing the needs of the community and their priorities, minimizing the dissatisfaction rate, and supporting innovative ideas. Therefore, diverse and innovative ideas are needed to engage more participants, increase the PB budget in some municipalities in Estonia, whose PB budget is still small, and align projects with the interests of participants to better address community needs.

The findings of this study revealed that the integration of blockchain technology in the PB significantly promotes transparency and increases citizen participation, thus reducing fraud and corruption and building trust in the system. This is particularly in line with the work of Mattei *et al.* [2], who emphasized the importance of designing PB processes that promote active participation of citizens, thus strengthening transparency and enhancing public trust. Similarly, the insights gained in this study are consistent with the drivers of citizen participation, such as the inclusive PB process, and the effective two-way communication identified by Manes-Rossi *et al.* [33]. Therefore, our blockchain-based model addresses these needs by proposing a transparent and decentralized platform to engage citizens in the budgeting process.

The results of this study indicate several key design elements that are important in improving the user experience and functionality of the e-PB system, including visually appealing, easy-to-access, and user-friendliness. However, the current platform, particularly the VOLIS system, lacks certain aspects of a user-friendly interface. The study also highlights the importance of visual representation and interactive elements in the presentation of data and the offer of real-time information. These findings align with the study of Mattei *et al.* who stated that designing a web page dedicated to PB is essential for sharing reliable information about the process. Integrating user-friendly features such as a progress bar showing the ongoing phase, a countdown demonstrating the time remaining until the end of the stage, and banners providing more details and links for different steps enhance the user experience by providing intuitive navigation throughout the e-PB process [32].

The results of the study evidenced that educational and awareness tools play a crucial role in e-PB. The use of these tools not only improves the citizen's understanding of the city budget but also promotes a collaborative approach between the government and citizens. Accessibility features in the e-Governance and e-PB systems are essential to foster an inclusive, transparent, and democratic society. The results of the study coincide with previous research that emphasizes the importance of these tools, which provide greater citizen empowerment and are fundamental to promoting the interaction between citizens and the administration [31].

The study revealed that the application of blockchain technology in e-PB systems could offer significant benefits, primarily due to the inherent properties of blockchain, such as decentralization, immutability, traceability, disintermediation, and transparency. The results support the findings of Mattei *et al.*, who confirmed that innovative DTs such as blockchains facilitate different aspects of PB, including identifying participants who are eligible for voting, engaging them in debates, and allowing them to vote [32].

Decentralization is a key feature of blockchain technology that could enhance the e-PB system by promoting transparency and fairness. The findings showed diverse views on this feature, ranging from optimism about its potential benefits to skepticism about its applicability in certain contexts.

Immutability, another fundamental feature of blockchain, ensures that the data recorded on the blockchain cannot be altered or tampered with. This study found that the immutability feature benefits voting systems by providing absolute guarantees of data integrity, increasing system security, and encouraging citizen participation. In addition, this study indicated that the immutability feature could increase transparency and citizen trust in the municipality and the e-PB system and improve the public reputation of the authority. These findings align with the study's assertion in [86] that blockchain's security features, such as public key cryptography, ensure the integrity and authenticity of the votes recorded on a blockchain-based system. The immutability feature of the blockchain ensures the prevention of double voting, which is achieved by using smart contracts that track vote duplication.

Traceability is another significant feature of blockchain technology that could greatly benefit e-PB systems. The ability to trace and verify transactions and data on the blockchain can lead to efficient and accurate tracking of budget allocation and spending, thereby reducing fraud and corruption risks. The study also highlighted the importance of traceability in systems, particularly in the voting and e-PB processes, to ensure transparency and accountability, thus building trust in the system, the municipality and the government. This finding is consistent with the study of Mattei *et al.*, who demonstrated that the presence of a platform is crucial to allowing citizens to track the progress of projects they voted on, thus building trust in citizens as they see the execution of their priorities being acted on. A good user-friendly interface facilitates better tracking for the voted project. The administration could explain any delays in the implementation of the project and periodically update the status of the project, thus ensuring the commitment made to the citizens [32].

Disintermediation is the operation of blockchain systems without the need for intermediaries or middlemen, benefiting the local government by lowering the costs and complexity of the budgeting process, as well as increasing the speed and efficiency of transactions and data exchange. Our findings highlighted that disintermediation removes intermediaries, simplifies processes, reduces the risk of errors or manipulation, and increases transparency and trust in the system. However, some level of intermediation is needed to ensure the quality of the idea and the adherence to the rules. Our findings in relation to the integration of blockchain in the existing legacy system align with the findings of Saxena *et al.*, who indicated that incorporating blockchain technology into e-Government services improves the effectiveness and efficiency of public service delivery, while maintaining the privacy of

online transactions [68].

We highlight how the inherent features of blockchain, such as traceability, transparency, immutability, disintermediation, and decentralization, address the identified challenges as indicated in Table IV.

In Figure 4, we propose the conceptual model of e-PB based on blockchain and highlight its potential to address the key challenges identified in this study. The model integrates the core characteristics of blockchain – decentralization, immutability, traceability, and transparency — each of which directly reflects the improvements observed in our findings. Our proposed conceptual model integrates blockchain technology with the existing e-PB system in Estonia to address the uncovered challenges and establish a transparent, efficient and inclusive blockchain-based e-PB model. This conceptual model is based on a consortium blockchain with a Practical Byzantine Fault Tolerance (pBFT) consensus protocol, which is a voting-based consensus algorithm suitable for permissioned or consortium blockchains where the number of validators is limited. The energy consumption in Proof-of-Work (PoW) is high and has limited throughput. Unlike PoW, the Byzantine Fault Tolerance (BFT) consensus protocol has low energy cost, low latency, and immediate finality. Most governments widely employed or piloted permissioned blockchains and use BFT and other widely used variations of BFT protocols such as pBFT as their secure consensus mechanism. Therefore, these types of protocols allow the nodes to communicate with each other in several rounds of voting to reach an agreement on the order of transactions, forwarding these transactions and their order to all other nodes in the network [87]. The pBFT consensus mechanism works well with only a small consensus group size, which can be considered as its drawback. None of the existing consensus protocols are perfect, as there are always certain trade-offs related to performance, scalability, and efficiency, thus the trend is shifting towards a hybrid approach where more than two consensus protocols are used for implementation [88]. The consensus mechanism guarantees a P2P network, establishing mutual trust between nodes (users), transmitting information through broadcast, and ensuring computing power using an incentive mechanism to promote the continual operation of the network [89].

Smart contracts can be used to issue and distribute incentives and prevent disputes automatically during incentive distribution. The findings in [90] identified blockchain-based incentive mechanisms as monetary, non-monetary, and hybrid, where non-monetary incentives were further classified into 1) credit-based incentives, 2) reputation-based incentives, and 3) gamified incentives. Among these incentive mechanisms, the monetary incentive and hybrid incentive motivate nodes effectively to participate in the blockchain system. However, the hybrid incentive mechanism works well not only in motivating users to participate but also in encouraging them to cooperate. Therefore, the hybrid incentive mechanism significantly motivates participation and cooperation in various contexts [90].

The governance token is a type of utility token and digital asset based on blockchain technology, providing the right to vote or the ability to make proposals [91]. Governance tokens decentralize decision making by distributing power to the community within a decentralized system, enabling token holders to vote via smart contracts on various proposals and budget allocations and deciding how these funds are utilized. This ensures a transparent and democratic process, allowing token holders to influence the management and direction of a project [92]. All projects that were analyzed by the study in [93], integrated utility tokens for various monetary and non-monetary incentive mechanisms. Monetary incentives are offered through rewarding tokens, and payment, and non-monetary incentives are participation in the governance process, and access rights to products, services, or resources.

Our conceptual model integrates utility tokens and governance tokens to provide citizens with access rights to products, services, or resources, allowing them to vote on budget allocations and different proposals using smart contracts in a decentralized manner. The participants are incentivized by rewarding utility tokens, which include monetary and non-monetary values, playing important roles in the public sector in motivating stakeholders to participate in the e-PB system. The smart contract is used to automate and ensure fair distribution of token-based rewards to citizens who actively participate and contribute. Therefore, a monetary incentive encourages citizens and increases their willingness to participate and contribute to the e-PB process.

In the following scenario, we explore how our blockchain-based e-PB conceptual model enhances citizen participation by integrating utility and governance tokens. Annika is an Estonian citizen who participates in a blockchain-based e-PB process in Tallinn, Estonia, and earns tokens for her contributions and participation. She submitted her proposal to improve the facilities of the local park and has been rewarded with 10 utility tokens from the system. She joins the discussion phase and discusses with other citizens about the value and impact of the project being implemented in the community, thereby providing valuable feedback and earning an additional 5 tokens. After that, projects that are innovative and beneficial to the community are put to the vote. Annika casts her vote on various projects, a maximum of three votes for three different proposals, and earns 5 utility tokens for each vote she casts, motivating her to actively and continuously participate. Consequently, she can use her tokens as a gift card to get discounts on public transportation between cities. Each token is valued, for example, one euro, which is a tangible incentive for participation in e-PB. This monetary incentive mechanism makes the e-PB process more attractive, particularly to younger citizens, increasing citizen participation. In addition, the gamified incentive can also be integrated into the blockchain-based e-PB system to offer badges to participants to showcase their contributions, fostering youth motivation to participate. Finally, integrating utility and governance tokens into the e-PB system fosters a sense of community and civic responsibility, particularly among younger citizens.

We map the current e-PB processes from multiple centralized platforms to a single blockchain-based system and added two more steps, public discussion and feedback gathering, to address the identified challenges. Furthermore, The

TABLE IV
BLOCKCHAIN'S INHERENT CHARACTERISTICS AND THEIR BENEFITS IN ADDRESSING THE IDENTIFIED CHALLENGES.

No.	Identified challenges	Blockchain features	Blockchain benefits
1.	No fund allocation tracking	Traceability	• This feature allows stakeholders to trace the flow of funds easily, ensuring that resources are utilized as intended.
2.	Low citizen participation	Disintermediation	• This feature prevents delays and additional incurred costs by removing intermediaries and encouraging direct citizen participation in governance and decision-making processes.
3.	Manipulation	Immutability	• This feature ensures that once data is stored on a blockchain, it cannot be tampered with, preventing manipulation.
4.	Lack of appropriate means for feedback gathering	Transparency	• This characteristic allows for open feedback mechanisms and ensures that all feedbacks are visible and accounted for.
5.	Transparency issues	Transparency	• This allows citizens and other stakeholders to see all transactions and processes, and monitor the fund allocation and usage transparently.
6.	Non-user-friendly interface	Smart contract (SC)	• SC automates processes, making interfaces more user-friendly and minimizing manual intervention.
7.	No project cost estimation	Smart contract	• SC automatically calculates costs based on predefined rules and conditions, reducing the risk of human error.
8.	Bureaucratic process	Decentralization	• This feature distributes control over the blockchain network, facilitating decision-making collaboratively, and reducing bureaucratic delays.
9.	Legacy system	Decentralization	• This reduces reliance on outdated legacy systems by distributing control across multiple nodes.
10.	Ineffective community outreach strategy	Decentralization	• This enhances community engagement by providing direct access to information and resources.
11.	Information barrier	Decentralization	• This ensures that information is accessible to all participants, reducing information barriers.
12.	Inclusivity issues	Decentralization	• This promotes inclusivity by allowing equal participation from all members.
13.	Need for civil society development	Decentralization	• This empowers civil society by providing tools and resources for development and collaboration.
14.	Multiple e-PB system	Decentralization	• This allows multiple systems to interact and share data without relying on a central authority.
15.	Lack of digital space for public discussion	Decentralization	• This enables citizens to discuss with each other using e-forums in a P2P manner, encouraging them to participate actively.

blockchain-based e-PB system fetches demographic information of registered residents from the e-population register portal through a Representational State Transfer Application Programming Interface (RESTful API). Restful API is an interface and a software architectural style that allows two computers or systems to securely exchange information over the Internet. The blockchain-based e-PB system should check the eligibility of voters to determine whether a voter is a registered inhabitant of the current region and 14 years old or older. As a result, demographic information such as age, gender, and other non-sensitive information from the e-population register is retrieved and displayed using visual elements such as bar charts and graphs on the blockchain-based e-PB system. This shows the proportion of votes cast by age groups, genders, and regions. This helps prevent votes cast by residents of other regions. The blockchain-based e-PB processes are illustrated as follows.

1. **Budget determination:** The local government determines the budget using the system user interface, and this budget amount is automatically stored on the blockchain. Our findings demonstrated that all transactions are visible and auditable by anyone, ensuring accountability and transparency in the allocation and use of public money, thus creating trust among citizens and the government.
2. **Idea submission:** Each eligible citizen at least 14 years old and registered as resident of the relevant municipality submits his ideas using the system and these ideas are automatically recorded on the blockchain by a smart contract.
3. **Public discussion/deliberation:** This step encourages citizens to actively participate and allows them to discuss and agree with each other on the proposals that best serve the needs of the community in a centralized P2P network without the need for intermediaries. All submitted ideas are visible to the participants of the network, thanks to the transparency feature of blockchain technology. This phase allows participants to use the 'like' mechanism to support proposals (ideas) that meet the community's needs or comment on ideas. Therefore, creating a digital space for discussions in a P2P network promotes decentralization, leading to greater citizen participation by mitigating bureaucratic obstacles.
4. **Expert evaluation:** The expert committee evaluates the feasibility of proposals to determine whether the idea is feasible to implement if it wins. Therefore, all decisions that are made by the expert evaluation committee can be audited by any participant in the system, increasing the transparency in the e-PB process.

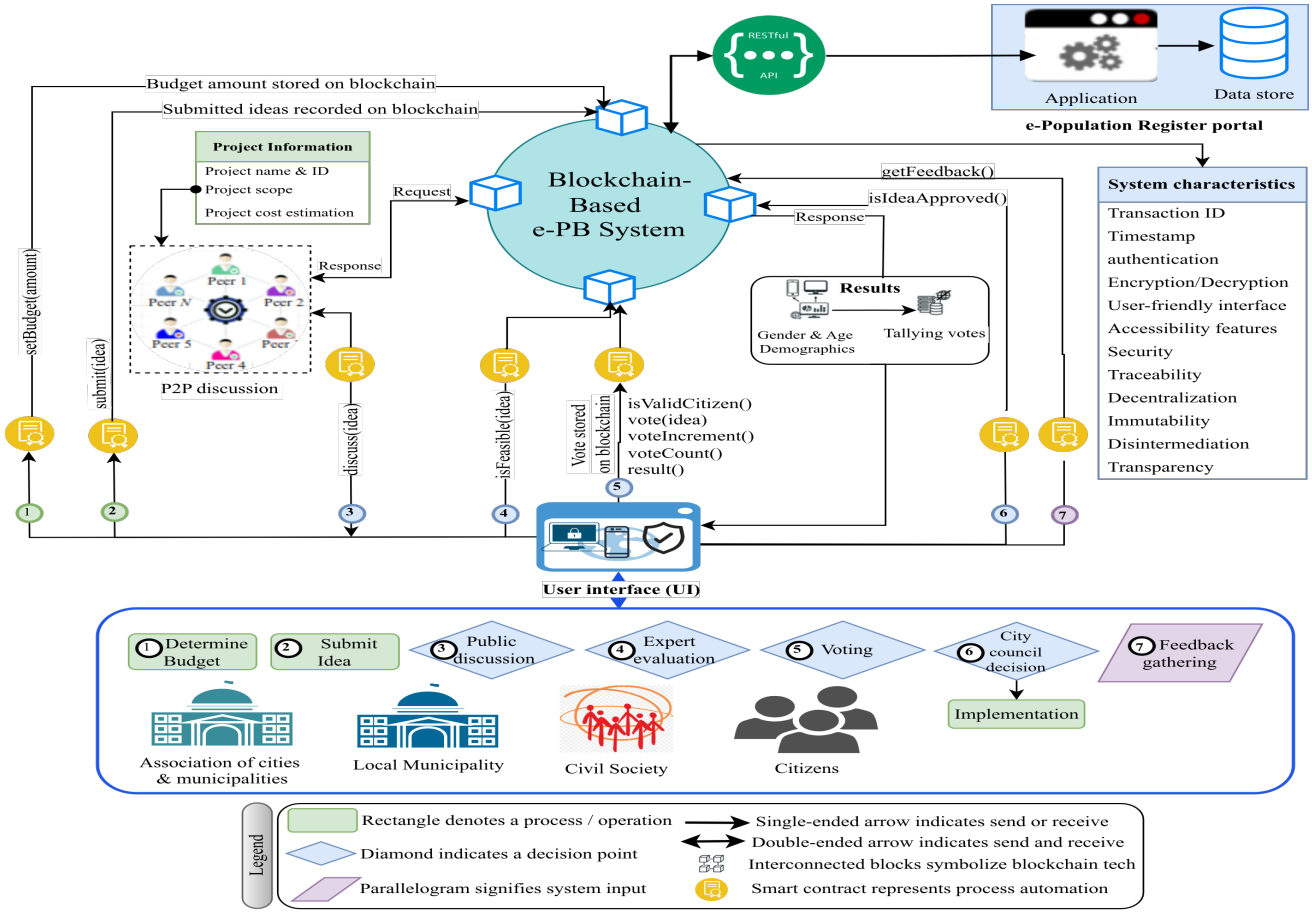

Fig. 4. A conceptual e-PB model utilizing blockchain technology in the TO-BE state.

5. **Voting:** Citizens vote on the selected proposals that are recorded on the blockchain. The voting criteria are validated through smart contracts. The system will publish the voting results using visual elements, such as graphs, demonstrating vote counts for each project that include the gender, age, and demographics of the voters, while ensuring their anonymity. The voting phase is carried out by logging into the system using an ID card to authenticate the citizens before voting, and citizens are verified by their residential place to be eligible to vote in their local municipality. Once a vote is cast and recorded on the blockchain, it cannot be changed or deleted; therefore, the voting process is transparent and can be audited by anyone.
6. **Implementation:** The city council approves the winning ideas and implements them.
7. **Feedback gathering:** This phase allows citizens to provide their feedback to the city council on the implementation of the project. Once the projects have been implemented and are in operation, feedback is collected from citizens. This allows the municipality to understand the perspectives of the citizens on the projects implemented and to make improvements for future initiatives.

In the public discussion, deliberation, and feedback gathering phases, we consider the following functionality in a smart contract.

- Project Identifier: A unique identifier for the project about which the feedback is about.
- User Identifier: A unique identifier for the user providing the feedback. This could be anonymized to protect the user's privacy.
- Rating: A star rating for the project. This could be on a scale (for example, 1 to 5).
- Comments: A text field for the user to provide more detailed feedback or suggestions.

The contribution of this study is twofold, addressing both the literature on engineering management and practical applications. In terms of practical application, the study:

- Proposes a blockchain-based conceptual model to address key challenges, including lack of public deliberation, insufficient transparency, low citizen participation, and inclusivity issues in e-Participatory budgeting by employing mechanisms such as real-time fund tracking, token-based incentives, and peer-to-peer discussions.
- Delivers practical guidance for government, developers, policymakers, and practitioners on leveraging blockchain technology to modernize the e-PB system.
- Explores the challenges of PB and the use of blockchain in various economic and cultural contexts to enhance the generalizability of the current findings and the ap-

plicability of the proposed conceptual model. This offers actionable insights for designing a transparent, inclusive, and secure blockchain-based solution in the e-Governance domain.

From an engineering management literature perspective, the study:

- Fills the gap in knowledge by exploring how blockchain's core features (e.g., transparency, traceability, immutability, decentralization, and disintermediation) can address key challenges identified in the existing e-PB system in Estonia.
- Extends the literature on e-Governance and blockchain adoption by proposing a conceptual model tailored to PB processes.
- Highlights the importance of cross-cultural considerations in blockchain adoption, contributing to knowledge on technology implementation in diverse socio-political and economic contexts.
- Identifies important design elements required for the successful deployment of blockchain systems in e-PB, contributing to human-centric system design in engineering management.
- Provides actionable guidelines for engineering managers and policymakers on blockchain adoption, including strategies for incentivizing citizen participation, enhancing inclusivity, and automating administrative workflows.

The implications of this research are presented below.

- **Theoretical implications:** This study offers theoretical implications for future research to test the proposed blockchain-based e-PB model in various socio-economic and cultural contexts to validate its generalizability. In addition, exploring the integration of cutting-edge technologies such as artificial intelligence with blockchain could further enhance the efficiency and impact of e-PB systems.
- **Managerial implications:**
  - PB project managers and local government authorities can streamline and automate various aspects of PB using blockchain technology and smart contracts, reducing administrative costs and overhead and increasing the effectiveness of PB.
  - The risk of fraud and errors can be minimized by automating e-PB processes such as proposal submission, voting, fund allocation, and tracking expenditures, leading to more effective resource management and better outcomes for PB projects.
  - Managers can make more informed decisions and respond quickly by receiving real-time blockchain data that increases the overall effectiveness and accountability of public institutions.
- **Practical implications:** This study provides practical implications for the implementation of blockchain-based solutions in the e-Governance domain. This is invaluable for developers, policy makers, and practitioners who are considering promoting the effectiveness of PB practices through the creation of a user-friendly DApp to increase accessibility, inclusivity, participation, and decentralized decision-making.

In conclusion, the findings of this study highlight several technical and non-technical challenges, demotivating factors, design elements, and benefits of the blockchain-based solution and the need for significant improvements in the e-PB system in Estonia. The integration of blockchain technology could potentially address some identified challenges and improve the system's transparency, reliability, and efficiency. Consequently, we consider designing a comprehensive e-PB model on blockchain technologies as future research using the design-science research method to increase degree of citizen participation and achieve transparency.

VI. Conclusion

This study explores the potential of blockchain technology to revolutionize the e-Participatory Budgeting (e-PB) process in Estonia. The findings reveal that blockchain technology ensures transparency by making transactions publicly visible to network participants, enhances citizen participation by rewarding incentives, and achieves inclusivity by facilitating equal participation, decentralized discussion space, and user-friendly decentralized applications (DApp) in e-PB systems. The study also identifies key challenges of traditional e-PB, including *no fund allocation tracking*, *lack of public deliberation/discussion*, *low citizen participation*, *transparency issue*, *manipulation*, *insufficient feedback gathering*, *information barrier*, *inclusivity issues*, and *non-user-friendly interface* receive the highest score considered as the major challenges. These are followed by minor challenges that receive the lowest score, such as *lack of project cost estimation*, *bureaucratic process*, *legacy system*, *ineffective community outreach strategy*, *multiple e-PB platforms*, and *need for civil society development*, respectively. In addition, the findings uncover factors that discourage youth participation in the e-PB process, resulting in lower citizen participation. These factors include *youth opinion not heard*, *lack of trust*, *lack of strong youth community*, *similar project & ideas*, *little value for the winning project*, and *delay in project implementation*. The study also describes the importance of design elements such as *user-friendly interface*, *visual data representation*, *education & awareness tool*, and *accessibility features*, which are essential to the effectiveness and inclusiveness of the e-PB system. Finally, the findings demonstrate how the inherent features of blockchain, such as immutability, traceability, transparency, decentralization, and disintermediation, benefit the e-PB processes and address identified challenges.

The research method we utilize is a holistic and multi-case study research method in software engineering. Participants (n = 16) of this study were recruited for semi-structured interviews using a snowball-purpose sampling technique. The sample included local government officials from several municipalities (that is, Rapla, Lääne-Nigula, Saue, Tallinn, and Tartu), citizens, IT and / or PB project managers, and an expert in e-democracy from the e-Governance Academy (eGA). The qualitative data from the interviews we analyze using the R Package for Qualitative Data Analysis (RQDA) with a

deductive thematic analysis method to identify, analyze and report topics based on research questions.

This study contributes to the existing literature by indicating how the use of blockchain technology and its inherent features, and smart contracts, addresses the challenges faced by traditional e-PB platforms and unifies disparate e-PB platforms into a single transparent and inclusive system. In addition, this study proposes an e-PB conceptual model that uses blockchain technology and smart contracts to enhance the effectiveness of e-PB. This research offers theoretical, managerial, and practical implications as follows. First, we test the proposed blockchain-based e-PB model in various socio-economic and cultural contexts to validate its generalizability. Second, using blockchain technology, project managers and local government authorities can automate and streamline different aspects of PB such as proposal submission, voting, and tracking fund allocation, thus reducing administrative cost and increasing the efficiency of PB. Third, implementing blockchain-based solutions in the e-PB domain is invaluable for developers, policymakers, and practitioners to consider improving the effectiveness of PB practices by creating a user-friendly DApp to increase accessibility, inclusivity, participation, and decentralized decision making.

Although this research provides an essential understanding of how blockchain technology can be incorporated into e-PB systems, it primarily relies on a multiple case study methodology. This constrains the broader applicability of our results. To overcome this issue, subsequent studies should utilize various research methods, including experimental designs and quantitative surveys, in different demographic and geopolitical settings to confirm and expand our findings. The proposed blockchain architecture outlined in the discussion section warrants a detailed evaluation to assess its practical implementation challenges and performance metrics. Essential aspects to be assessed are scalability, transaction capacity, and the effectiveness of the consensus mechanism, all of which are vital for confirming the system's suitability in practical situations. Open issues such as the scalability of blockchain solutions in PB, resistance from traditional systems, and barriers to technological literacy remain significant challenges. Future studies should also explore these dimensions in greater depth.

We recommend that subsequent efforts transcend the existing framework through the creation of a blockchain-driven e-procurement model, employing user-centric design principles and design science research approaches. This model should focus on improving transparency, combating corruption, and improving citizen engagement in public budgeting. Moreover, integrating advanced cryptographic techniques could further secure and privatize citizen interactions in e-Governance systems. The advanced digital infrastructure in Estonia and its progressive approach towards e-Governance make it a suitable environment for deploying blockchain-based solutions. However, we consider adopting the principles and benefits of this study in the PB setting of other countries such as Lithuania with appropriate adaptations.

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APPENDIX A
SEMI-STRUCTURED INTERVIEW PROTOCOL

Email to recruit relevant participants for the current study.

*Subject:*Request for an interview on e-participatory budgeting

Dear Sir/Ma'am,

I am *[name of researcher]* a doctoral student at *[name of]* University. I am conducting a case study to identify the deficiencies in the AS-IS state (current state) of the e-participatory budgeting (e-PB) model from the perspectives of various stakeholders, such as citizens, local government administrators, and developers. Based on the findings, we aim to develop a user-centered design conceptual model for our blockchain-based solution in the TO-BE state.

We will target the following groups of participants for our study:

- Citizens who have participated in the e-PB process in Estonia.
- Local government employees who are responsible for administering the e-PB process in their municipalities.
- Developers or system administrators who manage the systems for conducting e-PB projects.
- Expert in e-Democracy and have experience and involvement in projects that focused on e-participation.

Please let me know if you could provide your availability for an online interview.

Best regards
Researcher name

After receiving positive responses from participants, we sent an email attaching consent form that contains participation and recording consent form assuring the participant's confidentiality and anonymity. Moreover, the consent form consisted of links to two videos illustrating how blockchain technology and smart contracts work, thereby providing awareness for participant on integrating blockchain technology and smart contracts into the current e-PB model.

APPENDIX B
CONSENT FORM

The following two videos provide a concise introduction to blockchain technology and its smart contract applications, offering valuable insights to help you familiarize yourself with these concepts:

1. https://youtu.be/SSo_EIwHSd4?si=_LjJ4zyxzleBiend
2. https://youtu.be/ZE2HxTmxfrI?si=qk0D1qV9FlBQ8SIY

A. **Consent information letter**
This interview is conducted with local government representatives, developers/system administrators, and Estonian citizens who have participated in e-Participatory Budgeting projects in Estonia. *[name of researcher]* is a doctoral student of *[name of school]* at *[name of]* University and can be contacted at *[email]*; +372 xxx yyy zz. We would like to emphasize that:
- your participation is entirely voluntary;
- you are free to refuse to answer any question;
- you are free to withdraw at any time.

The interview will be kept strictly confidential and will be made available only to members of the research team of the study, or in case an external quality assessment takes place, to assessors under the same confidentiality conditions. Excerpts from the interview may be part of a final research report, but under no circumstances will your name or any identifying characteristic be included in the report.

B. **Recording consent form**
Thank you for participating in our case study. We will be recording the interview to allow the researchers to use this recording for transcription and data analysis purposes. Please read the statement below and digitally sign. I understand that my interview session will be recorded. I grant researchers permission to use this recording for transcription only, to analyze data for the current case study.

Digital Signature

APPENDIX C
INTERVIEW QUESTIONS

Interview general questions

1. Is it possible to track the allocation of funds in e-Participatory Budgeting projects within the current e-PB system?
2. Is participation in e-PB processes open to all social groups?
3. How does the existing e-PB model address inclusivity concerns in participatory budgeting processes within your local municipality?
   Probes: To create a truly inclusive PB process
   - 3.1 Low-income residents, people of color, and people who have been historically marginalized and excluded from decision-making must be well represented on the steering committee and as budget delegates.
4. What factors contribute to the lack of motivation among Estonian youngsters to participate in the e-PB process?
5. From your perspective, how transparent is the current e-PB model?
   Probes:
   - 5.1 Is there enough degree of citizen involvement in decision-making?
   - 5.2 Are citizens meaningfully involved in the governance process?
   - 5.3 Are all the processes of the e-PB project open, understandable, and transparent to the citizens?
   - 5.4 Are the transparency and openness of the project guaranteed at all stages?
   - 5.5 Are there enough possibilities for the citizens to give feedback about the project?
6. What potential challenges do you see in the existing e-PB model?
7. How citizens are encouraged to engage in discussion and contribute their ideas beyond simply submitting their proposals?
8. Can you describe your experience with the participatory budgeting process in your municipality, particularly in terms of public deliberation?
9. Were there any specific platforms or methods utilized to facilitate meaningful online deliberation, and if so, how effective were they in promoting dialogue and collaboration among participants?

Specific questions for local government officials and e-GA Senior Expert on e-Democracy

10. In your role, how would you describe the current level of inclusivity and decentralization in the budget preparation process within local government?
11. From your perspective, what challenges or issues have you observed in the current budget preparation process that could be addressed by implementing decentralized decision-making processes in an e-participatory budgeting model?
12. Could you point out any particular bureaucratic aspects within the current budget preparation process that you think might hinder a more inclusive and decentralized decision-making process?
13. Which specific design elements such as a user-friendly interface, visual representation of data, interactive elements, education and awareness tools, accessibility features, and a well-designed feedback mechanism could be most effective in increasing citizen participation?
14. What potential benefits do you foresee for the local government in adopting an e-PB model that is characterized by immutability, traceability, decentralization, and disintermediation?

Specific questions for the Developer/system administrator

15. How could features like decentralization, immutability, transparency, disintermediation, and security enhance transparency and efficiency in e-participatory budgeting processes?
16. What technical challenges and considerations need to be addressed to ensure transparency when developing a decentralized e-participatory budgeting model?
17. Do you think that features such as immutability, traceability, decentralization, security, and disintermediation would be most suitable for ensuring transparency and accountability in the context of e-participatory budgeting?
    Prompts:
    - 17.1 Immutability: The stored data on blockchain cannot be altered by anyone, and is safe from manipulation.
    - 17.2 Traceability: The transaction and data on the blockchain can be traced by network participants.
    - 17.3 Decentralization: It refers to the distribution of authority, resources, and responsibilities across the network, rather than being controlled by a single entity.
    - 17.4 Disintermediation: Blockchains operate without the need for trusted third parties, or middlemen.
    - 17.5 Transparency: All transactions are visible in the network for participants.
18. How would you suggest designing an e-participatory budgeting system that integrates features like immutability and traceability, enabling citizens to effectively monitor and track allocated funds?

Specific Questions for Citizens

19. To what extent do you think incorporating the decentralization feature into the e-participatory budgeting model could enhance your interest and willingness to participate in the process?
20. How do you currently perceive the transparency of the e-participatory budgeting process, and do you believe that the visibility of all transactions by participants in the network would positively impact these aspects?
21. In your opinion, could adding the disintermediation feature to the current e-PB system be most effective in increasing citizen engagement in e-participatory budgeting?
22. What are the main factors that have discouraged citizens from actively participating in e-participatory budgeting?

23. How do you think adding features such as immutable traceability, decentralization, and disintermediation features could address low citizen participation or lack of motivation?

Many thanks for sharing your insights and experiences with us today. Before we conclude, is there any feedback for us on the interview process, interview questions, or anything else you would like to share?