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Blockchain-based donations traceability framework

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ABSTRACT

The rapid growth of modern technologies has encouraged non-profit organizations (NPOs) to harness such technologies to better serve the charity sector, especially in relation to charity donation processes. Non-profit organizations primarily rely on fundraising that may involve opaque operations, which leads to the exacerbation of fears that donations may be used for illegal purposes or not reach deserving people. The necessity of charity donations traceability system is inevitable to overcome such concerns, which have an adverse impact on doners' trust in the donation process. In this study, we propose a blockchain-based donation traceability framework intended to enable all involved parties to trace the progress of charity donations from the moment they are given by donors to the moment they reach the intended recipients. The system is built on a public-permissioned blockchain on the Ethereum platform, with every transaction being recorded as a block in the chain. These blocks of information are immutable and visible to all parties, and they also enable timely and traceable transactions. The proposed framework's effectiveness is evaluated using a hybrid qualitative approach and proves to improve the traceability of charity donations overcoming the uncertainty associated with current systems.

1. Introduction

Charity donations represent a social solidarity approach used to promote cooperation, improve the economic and social status of communities, and enhance relationships among all members of society (Bensaid et al., 2017; Hall, 2017). Yet, the charity donation process involves the circulation of huge amounts of money, 70 % of which has been donated by individuals, which means that it needs to be closely monitored and controlled (Farooq et al., 2020).

More specifically, charity donations are made, managed, and received by various parties involved in the donation process, which is typically managed by non-profit organizations (NPOs) as part of their efforts to achieve both humanitarian and social objectives (Arshad et al., 2015). These NPOs principally depend on government support and financial contributions made by individual donors (Ranganathan and Henley, 2008). However, as many NPOs operate in complex environments, it can prove difficult to track where the financial support they receive ultimately ends up (Arshad et al., 2015). Moreover, NPOs generally need to use some of the donations they receive to cover their operating costs (Petrovits et al., 2011). As a consequence of such issues, donors often lack knowledge of the intended recipients, where their donations actually go, and how their donations are spent (Farooq et al., 2020).

With regard to the processes associated with charity donations, improper management, lack of transparency, and non-disclosure can all have a negative impact on the parties involved (Arshad et al., 2015), which may result in the loss of donors' trust (Hyndman and McConville, 2016), thereby adversely affecting the willingness of people to donate to charity. Another major issue related to the tracing of charity donations is the suspicion that charities sometimes falsely claim to pass on large amounts of money to the needy (Hyndman and McConville, 2016). Moreover, the possibility of charity donations being used to finance illegal or terrorist activities represents another significant issue (Romaniuk and Keatinge, 2018). In fact, the Financial Action Task Force has stated that charity donations should be considered the main source of terrorist financing worldwide (Laksmi, 2019).

Abbreviations: NPOs, Non-Profit Organizations; BBDT, Blockchain-Based Donation Traceability; Dapps, Decentralized Applications; IPFS, InterPlanetary File System.

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While various factors influence donors' donation intentions (Kashif et al., 2015), a lack of trust between donors and the other parties involved is the main reason why people refrain from donating to charity. A number of studies have identified trust as the most important factor in relation to the charity donation process (Evers and Gesthuizen, 2011; Taniguchi and Marshall, 2014; Torres-Moraga et al., 2010). In light of this, NPOs must seek to mitigate the risk associated with a lack of trust and avoid any weakness in terms of their financial planning and control in order to prevent donors from falling victim to fraud or abuse (Arshad et al., 2015). Moreover, NPOs should take steps to avoid any ambiguities or suspicions that may suggest the potential misuse of charity donations.

Thus, NPOs need to ensure the transparency and efficiency of their financial systems (Hyndman and McConville, 2016). The adoption of trustworthy and transparent systems should serve to ensure that all parties involved in the charity donation process, such as donors, needy parties, NPOs, and volunteers, can rely on a secure donation process that is not associated with any unsafe or illegal activities and guarantees the delivery of all donations to the intended recipients. The issue of traceability is highly important in this context, as it enables access to detailed information regarding every aspect of the overall charity donation process (Behnke and Janssen, 2020). The utilization of digital technology could offer tremendous benefits to the donation process through facilitating and improving the operations associated with it. Moreover, blockchain technology has the potential to address the opportunities, challenges, risks, and desired advancements within the charity sector, in addition to driving enhanced transparency, increased accountability, and improved performance.

Indeed, the use of emerging blockchain technology to develop a donation management system could increase charities' transparency (Hu and Li, 2020) and improve people's trust in their donation systems. A key technical feature of blockchain is the impossibility of any record being forged, altered, or tampered with. In addition, every transaction requires consensus among all the involved parties. As a result, the decentralized nature of blockchain renders data more secure, which suggests blockchain to be highly suitable for use in relation to transactions involving charity donations (Farooq et al., 2020).

In the present paper, we focus on answering the following question: How can we improve the traceability and transparency of charity donation processes using blockchain technology? To answer this question, we propose a blockchain-based donation traceability framework intended to improve both the traceability and the transparency of charity donations in order to promote trust between all the involved parties and guarantee that the donations reach the intended recipients. The framework is also intended to eliminate any ambiguities and suspicions concerning NPOs and their charity donation processes. Furthermore, a web-based system is developed based on the proposed framework to test its applicability and efficiency with regard to the tracing of charity donations. The developed system has proved to be easy to use and effective in eliminating all suspicious intermediaries and activities. It is also secure, which allows for safe transactions between all involved parties. The system allows for the allocation of funds according to the actual progress of each transaction as well as the continual updating of transactions, including guaranteeing of the authenticity of all relevant information.

As current donation systems lack many essential and desirable features, there exists a clear need to develop a dynamic, secure, transparent, and reliable charity donation system capable of gaining parties' confidence and trust through the use of blockchain's capabilities. The present paper makes the following important contributions to the literature and practice in the charity sector:

- Highlighting the significance of traceability in terms of eliminating the problems currently associated with charity donation processes.
- Proposing a blockchain-based donation traceability framework for charity donations that gathers and secures the information of all the parties involved in the donation process.
- Providing a means of storing information concerning charity donations in a transparent and decentralized manner, which will prevent the concealment of financial waste or participation in fraudulent activities.
- Combining theoretical concepts with practical applications in an effort to facilitate the availability of the most up-to-date and accurate details concerning charity donations.
- Enabling both backward and forward traceability using distributed ledgers and smart contracts, while also ensuring that all parties' identities are authenticated and protecting their privacy.

The remainder of this paper is organized as follows. Section 2 reviews the prior literature concerning blockchain technology and charity donations. Section 3 presents the proposed framework for tracing charity donations. Section 4 describes the implementation of the charity donation system that is built based on the proposed framework, while Section 5 evaluates the effectiveness and benefits of the proposed framework. Finally, Section 6 concludes the paper and suggests some possible avenues for future research.

2. Background

2.1. Blockchain

Blockchain is an emerging technology that has been the subject of significant research interest in recent years (Wüst and Gervais, 2018) due to having applications in relation to both financial and non-financial systems, including insurance, healthcare, and supply chain systems (Berdik et al., 2021). In addition, governments have implemented blockchain technology in an effort to speed up information management and automate various processes (Kassen, 2022). Moreover, the uses of blockchain have also grown within organizations seeking to increase their security and transparency as well as build trust between the various parties involved in their processes (Wüst and Gervais, 2018). The first use of blockchain was the Bitcoin cryptocurrency, which was developed in 2008 (Nakamoto, 2008). Since then, the uses of blockchain have increased rapidly, although much of the technology's potential remains undiscovered.

In recent years, Blockchain technology has brought significant benefits to the financial sector by contributing to automating and streamlining financial organizations, in addition to allowing businesses to enhance their transparency and build trustworthy systems (Ali et al., 2020; Chen et al., 2022). Importantly, the key reason for blockchain's popularity in the financial sector is the fact that it is secure and well tested when it comes to financial applications (Crosby et al., 2016). As a consequence, blockchain continues to have positive effects on the financial sector worldwide. For example, it facilitates the global transfer of funds without the need for additional costs such as currency conversion charges to be incurred (Trautman, 2016). In fact, McKinsey estimates that the cost of an individual transaction could be reduced from $26 to $15 through the use of blockchain technology (Guo and Liang, 2016).

Moreover, blockchain facilitates transparency and security by allowing for immutable, irreversible, and traceable transactions in real time, which serves to increase people's trust in the associated systems. Both control and management within organizations are affected by the very nature of blockchain, which entails regulations, policies, and laws being executed automatically and implicitly through established protocols and the system infrastructure (Ali et al., 2020).

The blockchain architecture involves a decentralized peer-to-peer network wherein each peer is a computer that holds a copy of the public ledger. Authority is distributed across all the peers within the network, meaning that third-party intervention is not required to complete financial processes (Ølnes et al., 2017). Simply put, blockchain comprises a chain of blocks. Each block stores the current transaction's hash in the Merkle root as well as the hashing for all the previous blocks. In addition, each block stores the nonce, which is a number that is used only once as a counter during the mining process (Nakamoto, 2008). The structure of blockchain is shown in Fig. 1.

Furthermore, blockchain uses distributed ledger technology, smart contracts, and consensus mechanisms to build a system that is more secure than traditional systems (Ølnes et al., 2017). The distributed ledger records the transaction details and is shared among all the peers on the network. This means that each peer has a full copy of the ledger, which reduces the level of dependency on one central node and prevents manipulation or system failure (Ølnes et al., 2017). The smart contract stores and executes the predefined conditions agreed upon by all the involved parties. Generally, smart contracts facilitate agreement between parties without the need for any central authority or third-party involvement (Ølnes et al., 2017). Finally, the utilized consensus mechanisms represent an agreement between peers to record another transaction on the blockchain network. They also guarantee that all the peers have identical copies of the distributed ledger. The two most commonly used consensus mechanisms are proof of work and proof of stake (Nguyen and Kim, 2018).

2.2. Charity donation traceability

A number of systems have previously been developed to collect, trace, and distribute charity donations. In this regard, many prior studies have focused on connecting the different parties involved in charity donation processes in an effort to facilitate the traceability of donations. For instance, (Rana et al., 2020) proposed a system that provided a portal gathering donors, needy parties, volunteers, and other parties (e.g., restaurants or hotels) seeking to donate clothes, books, and food to people who needed them.

Aishah et al. (2017), Elapanti and Pinthepu (2018), Pribadi and Pambudi (2021) all suggested the provision of a list specifying the items required by NPOs in order to facilitate their reach and ensure that only second-hand items still suitable for use were donated. They also positioned social institutions as the responsible receivers tasked with passing on donations to the needy.

Moreover, Almeida and Cunha (2018) sought to provide a system capable of guaranteeing that donations reach the needy. They developed a platform that connected donors with NPOs and traced the status of each donation while maintaining the donors' anonymity.

Mobile-based platforms have been of great benefit to the charity sector due to being easy to access and only requiring the use of inexpensive end devices such as tablets or mobile phones. Indeed, several charity donation applications have been developed to date. For instance, Mon et al. (2020) proposed and developed a prototype mobile application that allowed donors to donate directly to charity organizations. Similarly, Shelar et al. (2020) created a smart system based on distributed client–server computing technology intended to facilitate the donation of food, money, amenities, and clothes. To reduce the likelihood of scams, the system allowed donors to trace their donations.

Furthermore, the system proposed by Titarmare et al. (2020) was designed to facilitate the donation of all items to orphanages and nursing homes via a mobile application. It was also intended to help donors locate nearby orphanages.

As food scarcity remains a major concern in many countries worldwide, Elavarasan and Nesakumar (2019) and Krishnan et al. (2020) created Android applications designed to manage food waste and connect donors with the needy and other relevant parties. They suggested the use of quick response (QR) codes rather than manual data entry to ensure the validity of the information provided.

In addition, Panchal et al. (2020) developed the "Food For All" application to connect donors with volunteers from NPOs, who would then deliver leftover food to the needy before its expiry date passed.

With regard to the healthcare sector, Ali et al. (2015) and Talapatra et al. (2019) proposed blood donation management systems due to the rise in donation requests and the weak technology traditionally used to manage such donations. They focused on opening up a channel of communication between patients and blood donors in order to allow for rapid responses to emergency requests. Similarly, the system developed by Sumaryanti et al.

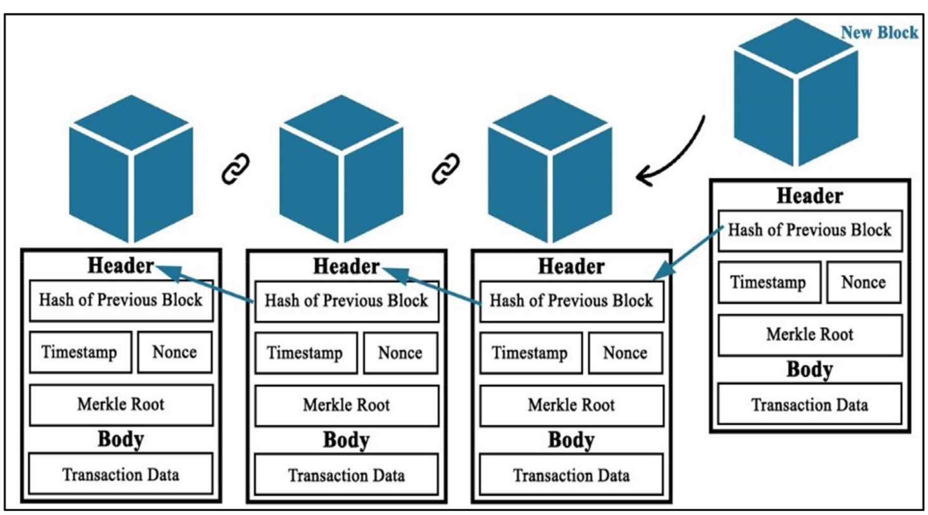

Fig. 1. Structure of blockchain.

(2018) provided real-time information on bloodstock and traced the nearest donor location by connecting different relevant parties, such as the staff of blood banks, needy parties, and donors. The system allowed for direct communication among all these parties via calls or messages.

Organ donation tracing has also been a subject of interest for many researchers and stakeholders. For instance, Pradhan and Mishra (2020) sought to provide an Android application that linked donors with individuals in need of organs by passing message requests between them without disclosing any details concerning their identities. Mostafa et al. (2014) proposed a framework based on both cloud and mobile computing that linked donors with blood banks and healthcare organizations in an effort to ensure that the correct blood type reached each needy individual.

Additionally, Mostafa et al. (2020) proposed a charity fundraising information model that established a connection between donors and recipients. Their model also involved blood banks and NPOs, and it facilitated the tracing of donors' records whenever required. Alshammari et al. (2017) presented a smart charity system based on the internet of things that could be used to monitor donations and notify charities about the levels of donations in their charity boxes, thereby facilitating the collection and distribution of charity donations.

2.3. Application of blockchain in charity donation systems

Despite various studies, models, and applications contributing to the development of charity donation systems, charity-related transactions continue to provoke concern and suspicion among donors. Following the emergence of blockchain technology, a few studies have investigated different aspects of the use of such technology in the field of charity donations. For example, Kshetri (2017) suggested blockchain technology to be a suitable solution for promoting trust and enhancing efficiency with regard to transactions concerning charity donations in developing countries.

In addition, Hamdani (2020) and Rejeb (2020) both investigated the management of mandatory charity donations in line with the Islamic practice of zakat. They sought to encourage the adoption of blockchain technology by zakat institutions with the objective of connecting all the involved parties on a single decentralized network through decentralized applications (Dapps). Their ultimate aim was to provide more reliable systems for the automatic execution of regulations and rules using smart contracts, and they suggested that self-executed smart contracts could be used to pay zakat after it had accumulated and remained in passage for one lunar year.

Moreover, Agarwal et al. (2018) proposed a system intended to increase the effectiveness of efforts to enrich society using blockchain, smart contracts, and cryptocurrency. Their system abolished the tradition role of intermediaries between donors and charity doers and facilitated the transfer of donations via the exchange of certificates, which were positioned as an asset containing information about noble deeds or work done for charity that could be used to obtain patronage and funding for charity work.

Lee et al. (2018) focused on the privacy aspect of blockchain use and presented a system based on both blockchain and smart contracts intended to increase the security of transactions and safeguard donors' personal information. They used a one-time account address system to protect users' privacy, thereby preventing the identification of either donors or recipients by other parties on the Ethereum network.

Trotter et al. (2020) proposed a blockchain-based model for facilitating the exchange of donations between donors and non-governmental organizations based on conditional giving, whereby donors' conditions could be attached to their donations. The donations would be automatically released once the established conditions were met.

In addition, Farooq et al. (2020) presented a blockchain-based charity management framework designed to ensure secure and auditable transactions by government authorities using the public-permissioned Ethereum blockchain. The framework proposed by Hu and Li (2020) addressed the lack of transparency and unnecessary difficulty associated with managing charity organizations with the objective of enhancing people's willingness to donate to such organizations.

Finally, Wu and Zhu (2020) studied the use of blockchain technology as a rapid and secure solution for charitable service operators during the COVID-19 pandemic, which gave rise to increased demand for donations as well as increased information asymmetry. This use of blockchain technology allowed the researchers to guarantee the authenticity and accuracy of information during the pandemic.

As only a few models and frameworks within the charity donation field have adopted blockchain technology, theoretical approaches remain the principal reference point when discussing and managing charity donations using blockchain as well as evaluating the core functions of such systems. The execution of a charity donation process involves many subprocesses connected to different people. Thus, the majority of prior studies concerning charity donations have sought to provide secure and trustworthy systems with which to perform charity donation processes. Yet, these systems all lack the ability to adequately trace donations, which would help to enhance donors' trust in the overall donation process. Indeed, donors want to know where their donations are going in real time, and they also want the identities of the needy parties participating in the system to be guaranteed. Therefore, we propose a system that facilitates both traceability and transparency by allowing transactions to be seen by all the involved parties. Moreover, all the parties can also check the validity of the transactions, which serves to prevent fraudulent processes (Nakamoto, 2008).

3. A blockchain-based donation traceability framework

To achieve a high degree of transparency and trust between the parties involved in charity donation processes, donations must be traceable by all concerned parties. We propose a blockchain-based donation traceability (BBDT) framework intended to enable all the parties to trace charity donations from the moment they are made by the donor to the moment they are received by the

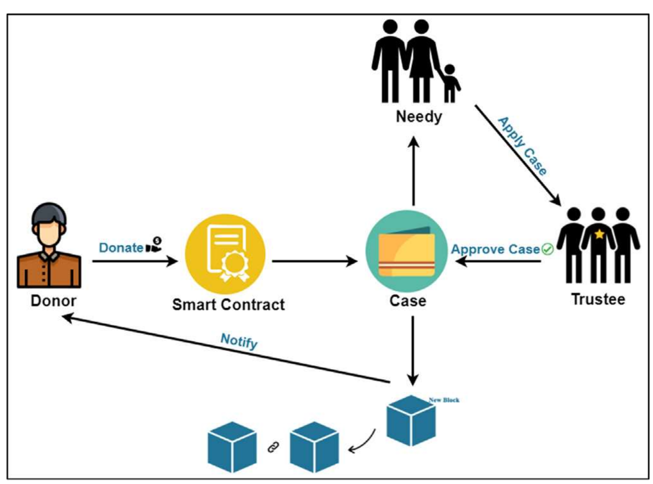

Fig. 2. Blockchain-based donation traceability framework.

Table 1
Features of blockchain-based charity donation systems.

Function	Party	Studies
Account registration	Donor, needy party, charity organizations	(Farooq et al., 2020; Hu and Li, 2020; Rejeb, 2020; Hamdani, 2020; Lee et al., 2018; Trotter et al., 2020; Wu and Zhu, 2020)
Make donation	Donor	(Farooq et al., 2020; Hu and Li, 2020; Rejeb, 2020; Hamdani, 2020; Agarwal et al., 2018; Lee et al., 2018; Trotter et al., 2020; Wu and Zhu, 2020)
Generate a certificate	Donor	(Agarwal et al., 2018)
Request help	Needy party	(Hu and Li, 2020; Wu and Zhu, 2020)
Notify donor	–	(Farooq et al., 2020)
Add conditions to donation	Donor	(Trotter et al., 2020)

intended recipients. Our aim is to automate the overall charity donation process and enhance the level of trust and transparency associated with it.

Fig. 2 presents the proposed BBDT framework, which involves three different parties: the donor, the needy party, and the trustee. Here, a trustee can be described as an organization within the BBDT system that holds a list of needy parties. In the proposed framework, the charity donation chain begins with the donor and ends with the needy party. It uses a public-permissioned blockchain to build a new charity donation traceability system. Moreover, the identities of the participants are guaranteed so as to achieve an authoritative, accountable, and unmodifiable system.

The proposed system uses a cryptocurrency wallet to generate public and private addresses for each party involved in a transaction. The public key is the identity of every party within the network, without prejudice to their personal identity (Haque and Rahman, 2020). The trustee and those included on the needy list need to be invited to join the network, which will prevent scammers from joining the network in an attempt to gain money. Furthermore, if a donor wants to join the network, they must send a joining request. After a donor's information has been validated, a verification code will be sent to them. All the parties will be connected on a single decentralized network, and each party will have their own blockchain account on the network.

The proposed system is capable of performing multiple functions associated with the tracing of charity donations. These functions were identified through a literature review and an analysis of all the functions detailed in prior studies involving charity donation systems. Table 1 lists the functions most commonly mentioned in the reviewed studies.

The proposed system focuses on ensuring transparency, trust, and efficiency with regard to the processing of charity donations by guaranteeing the real-time traceability of all such donations until they are received by the relevant needy party. Moreover, the system requires that all the involved parties be authenticated prior to being granted access to the system's functions. Both needy parties and trustees have the ability to create cases; however, all the cases created by needy parties must be approved by trustees before they can receive donations. In addition, donors have the ability to trace the progress of their donations throughout all the stages of the donation process.

The system's features are available to every party who has successfully joined the network. Fig. 3 presents the main features available to the different parties within the system. As shown in the figure, the main functions of donors are donating and tracing donations, while the main function of needy parties is creating new cases. Moreover, the main functions of trustees are creating new cases, accepting or rejecting cases, and tracing donations. Finally, the system notifies all the donors who have contributed to a particular case after that case has been completed. All the system's functions, including the different parties' access permissions, are detailed in Table 2.

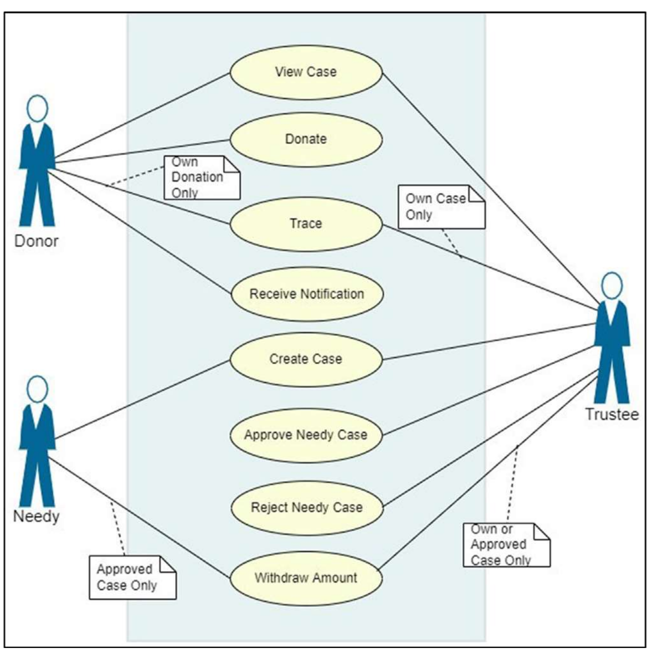

Fig. 3. Blockchain-based donation traceability system use case.

Table 2
Summary of the BBDT system's functions.

Function	Description	Permission
constructor	Initializes the object	System
join	Join all parties	Needy party, trustee, donor
approve	Approve after checking parties' identities	System
createCaseByNeedy	Create a new case	Needy party
createCaseByTrustee	Create a new case	Trustee
approveCase	Evaluate case as approved and add other case information	Trustee
rejectCase	Evaluate case as rejected	Trustee
donate	Donate to specified case	Donor
trace	Allow tracing of all cases in the system	Trustee, donor
getDonations	Allow tracing of donations in one case	Trustee, donor
getDonersByCase	Allow knowledge of donors in one case	Trustee, system
calcPercentages	Calculate administrative fee percentages	System
deposit	Deposit amounts to different parties' addresses	System
withdraw	Withdraw amount to a party's wallet	Needy party, trustee, donor
walletBalance	Retrieve party's balance in the system	Needy party, trustee, donor
SendNotification	Notify all the involved donors	System

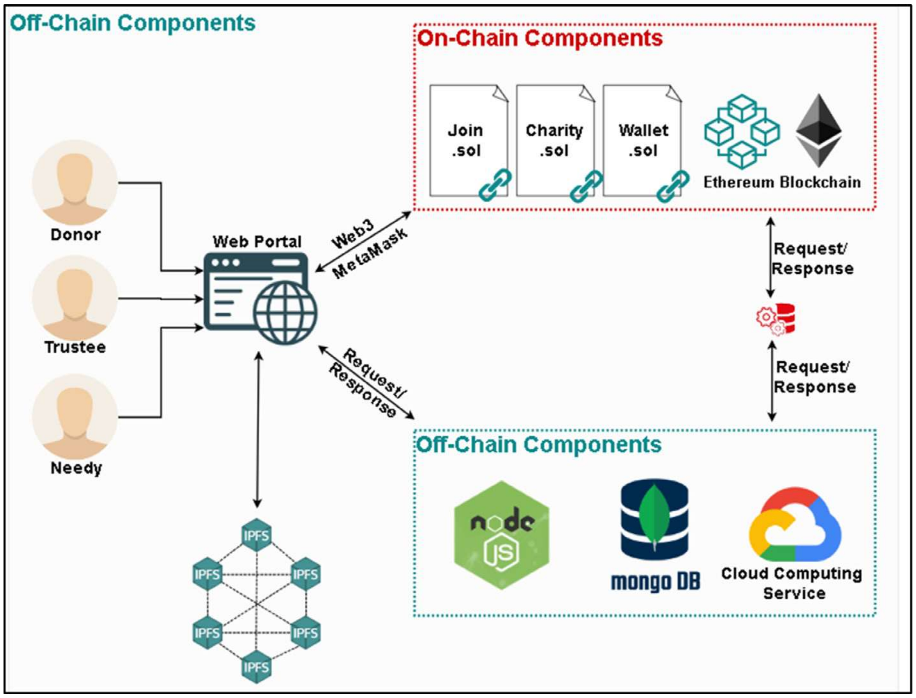

Fig. 4. System architecture.

4. Implementation

The proposed framework utilizes blockchain technology by building a public-permissioned Ethereum chain and then writing smart contracts using the Solidity language. The system integrates several different components to provide the required functionalities. Fig. 4 presents the architecture of the BBDT system, which is principally designed to trace charity donations and verify that the necessary conditions have been satisfied during the donation process.

The architecture shown in Fig. 4 reveals that the BBDT system is divided into on-chain and off-chain components. Furthermore, it highlights the dependencies among those components, which are accessible by the different parties involved in the donation process. The underlying reasons for using off-chain components include the need to store sensitive data in separate storage locations without publicly broadcasting the data on the network and the desire to increase stakeholders' anonymity and privacy (Zyskind and Nathan, 2015). As a result, each party's personal data will be represented by one address value that is undetectable and inaccessible by the other parties. In addition, the interactions among the parties will be based on their MetaMask addresses, which will prevent their identities from being revealed or their privacy being breached.

Thus, the proposed system will provide full anonymity to all the involved parties (Emmadi et al., 2018). More specifically, it will not disclose any sensitive or secret information on the blockchain network, except for the trustee being able to access each needy party's address and related information from the needy party list in order to evaluate the needy cases and assign new cases in the future. Moreover, the trustee will be able to trace all the needy party cases within the system.

Among the other reasons for using off-chain components is the fact that they reduce the user fees per transaction. Indeed, unlike blockchain transactions, off-chain transactions do not involve fees per transaction. They also decrease both the space used on the blockchain network and the lag time. In fact, without off-chain components, a long lag time may prove necessary, depending on the network load and number of transactions in the queue (Hepp et al., 2018).

The off-chain components of the proposed system include user interfaces developed by ReactJS, hosted and decentralized storage such as the InterPlanetary File System (IPFS), and other components used to notify donors after cases have been completed. All the transactions will be accomplished using MongoDB, node.js (Mühlberger et al., 2020), and web3 to create the interactions and verify them among the off-chain and on-chain components.

Furthermore, Truffle will be used to facilitate the development of the system as well as to compile, test, and deploy the smart contracts on the blockchain network. Therefore, the main on-chain component of the proposed system is the smart contract, which is used to execute all the rules stipulated within the system and so cannot be changed.

Many smart contracts have been developed to execute and accomplish system flows by attaching various conditions. They store information concerning both the parties and the interactions among them in a traceable manner, which enables efficient tracing and auditing in an effort to follow the movement of all donations until they reach the intended recipients. In this way, information concerning charity donations can be retrieved by the parties at any time, which facilitates compliance with relevant laws.

All the system transactions are centered on the relevant case and the associated donations. Here, a case represents a need on the part of a particular needy party, and completing it should serve to alleviate that needy party's plight. The key information concerning a given case or donation includes the case or donation identification (ID), needy party, description, status, time, target amount, current amount, and trustee. Both cases and donations can be traced at any time by using the blockchain to trace the progress being made.

The transactions are executed by parties who have joined the network. More specifically, they join and authorize transactions through the "join" smart contract. The "charity" smart contract provides a set of functions that enable the parties to make charity

```
Algorithm 1: Trustee and needy individual's functions
  If needy status == APPROVED
      function createCaseByNeedy()
      Input: _description
          Assign values to case variables(e.g. caseId,
          description)
          Change case status to PROCESSING
          emit createCaseByNeedyLog(nextCaseId,
          msg.sender, trustee, block.timestamp);
      End function
  else
      Revert
  If trustee status == APPROVED
      Function createCaseByTrustee()
      Input: _description, _targetAmount, _caseEvaluation
          Assign values to case variables(e.g. caseId,
          description, targetAmount);
          Change case status to EVALUATED;
          Evaluate the case (e.g. medium, or high, or
          critical);
          emit createCaseByTrusteeLog(nextCaseId,
          _needy, msg.sender, block.timestamp);
      End function
      Function approveCase()
      Input: _caseId
          Require Case status is PROCESSING
          Assign values to case targetAmount;
          Change case status to EVALUATED;
          Evaluate the case (e.g. medium, or high, or
          critical);
          emit approveCaseLog(_caseId, needy,
          msg.sender, block.timestamp);
      End function
      Function rejectCase()
      Input: _caseId, _targetAmount, _ caseEvaluation
      Require Case status is PROCESSING
      Change case status to REJECTED;
      emit rejectCaseLog(_caseId, needy, msg.sender,
      block.timestamp);
      End function
  else
      Revert
```

Fig. 5. Trustee and needy party functions.

```
Algorithm 2: Donor functions
  If donor status == APPROVED
      function donate()
      Input: _caseId
      Require Case status is EVALUATED
          Require (msg.value > 0)
          Assign values to donation variables(e.g. caseId,
          donationId, amount);
          if (currentAmount.add(msg.value) > targetAmount)
              Calculate refund =
              currentAmount.add(msg.value).sub(targetAmount);
              Add donation amount into case amount;
              Deposit{ value: refund }(donor);
              Deposit administrative fees using
              calcPercentages(amount, percentage, scale)
              }(trustee);
              Deposit needy amount using calcPercentages
              (amount, percentage, scale) }(needy);
              Assign value to case currentAmount;
              Change case status to COMPLETED
              emit donateLog(_caseId, msg.sender, msg.value,
              block.timestamp);
              emit closeCaseLog(_caseId, needy, trustee,
              block.timestamp);
          Else if (currentAmount.add(msg.value) ==
          targetAmount)
              Assign value to case currentAmount;
              Deposit administrative fees using calcPercentages
              (amount, percentage, scale) }(trustee);
              Deposit needy amount using calcPercentages
              (amount, percentage, scale) }(needy);
              Change case status to COMPLETED
              emit donateLog(_caseId, msg.sender, msg.value,
              block.timestamp);
              emit closeCaseLog(_caseId, needy, trustee,
              block.timestamp);
          else
              Assign value to case currentAmount;
              Deposit administrative fees using calcPercentages
              (amount, percentage, scale) }(trustee);
              Deposit needy amount using calcPercentages
              (amount, percentage, scale) }(needy);
              emit donateLog(_caseId, msg.sender, msg.value,
              block.timestamp);
      End function
  else
      Revert
```

Fig. 6. Donor functions.

donations, including managing those donations with a high degree of tracing-related detail. Each party performs certain functions based on the permissions listed in Table 2, which allow the parties to access specific functions. Fig. 5 presents the algorithm governing the trustees' and needy parties' functions, whereby the needy parties have access to the create a case, withdraw, and walletBalance functions. After a case is created by a needy party, it must be evaluated by the trustee via the approveCase or rejectCase function. In total, the trustee's functions are the createCaseByTrustee, approveCase, rejectCase, withdraw, and walletBalance functions. If a trustee creates a case, it will be available without the need for approval.

Fig. 6 presents the algorithm governing the donors' functions within the system, namely the donate, withdraw, and walletBalance functions. Importantly, to increase all the parties' trust in the BBDT system, a donor can use the withdraw function to refund any surplus if the donated amount exceeds the value required to complete the case.

During the execution of a transaction, all the donated amounts are locked by a smart contract, although the "charity" contract will preserve each amount for each party's address. Therefore, each party will be able to withdraw the specified amount to their wallet address without the need for a direct money transfer between the parties. The wallet operation is managed by the "wallet" smart contract, which has three functions, as shown in Fig. 7. The deposit function is implicitly used to allocate and distribute amounts among the respective accounts, which will later be pulled by the relevant parties.

An authorized party can read about the case and use the tracing feature to access information on both its progress and the received donations. This tracing feature reveals each case's status, how much still needs to be collected, and by whom it is being managed. Furthermore, due to knowing the number of donations made, the times they were made, and the amount of each donation, a donor

```
Algorithm 3: Wallet Functions
    function walletBalance()
        return address(this).balance;
    End function
    function deposit()
    Input: address _user
        balances[_user] =
        balances[_user].add(msg.value);
    End function
    function withdraw()
        require(balances[msg.sender] > 0)
        uint256 amount =
        balances[msg.sender];
        balances[msg.sender] = 0;
        msg.sender.sendValue(amount);
        emit Withdrawn(msg.sender,
        amount);
    End function
```

Fig. 7. Wallet functions.

can determine the previous donations made to each case. The algorithm governing the tracing of cases and donations is shown in Fig. 8. The two functions that comprise the tracing feature are the trace and getDonations functions, which trace all the chains of blocks in order to return all the required case information (Fig. 9).

```
Algorithm 4: Tracing Cases and Donations
    Input: CaseID;
    Output: Case detailed information;
    For each i-th block in the blockchain
        If CaseID ? i-th block
            Retrieve Cases details;
            Retrieve current block number;
                For each i-th block >= current
                block number;
                    If donations belongs to
                    CaseID
                        Retrieve Donations
                        details;
                        Hash from i- th block ?
                        Hash to (i - 1)- th block;
                    else
                        Hash from i- th block ?
                        Hash to (i - 1)- th block;
                End for
        else
            Hash from i- th block ? Hash to (i
            - 1)- th block;
    End for
```

Fig. 8. Traceability within the system.

Other libraries and contracts are also used to ensure the security of the BBDT system and prevent any security breaches. For instance, safeMath is used to perform Solidity's arithmetical operations safely, which avoids problems related to float values such as the underflow and overflow (Khor et al., 2020). An important function that may cause overflow without the use of safeMath is calcPercentages, which is implemented and called to execute the rule that the trustee who managed the case is entitled to receive a fixed percentage of each donation as an administrative fee, as set out in the smart contract.

In addition, ReentrancyGuard is used to prevent reentrant calls to any function, which increases the security of the smart contracts (Samreen and Alalfi, 2020). To decrease both the required development effort and the likelihood of errors during development, as well as to increase the efficiency and reliability of the system, the reusability feature is used (Guida and Daniel, 2019). Our smart contracts can also be reused in similar projects. Moreover, an OpenZeppelin library is used to execute tasks such as those related to managing the parties' addresses.

Following implementation, all the smart contracts are deployed and added as transactions within the blockchain. The BBDT system's interfaces can interact with the smart contracts due to knowing each smart contract's application binary interface and address.

Furthermore, all the transactions in the proposed framework are made in real-time between the parties. The Ethereum transaction fees determine the complexity of the codes. These fees are based on the total cost as measured in Gwei, wei, or ether units. The entity algorithms 1 and 2 make changes to different states and spend a certain amount of "gas" on each transaction. For example, the createCaseByNeedy function may spend 0.007954 ETH (7954000 Gwei), while executing the trustee's functions may cost 0.010981 ETH (10981000 Gwei).

Donors can spend either 0.009185 ETH, 0.008043 ETH, or 0.008944 ETH based on the main condition associated with the donation process, that is, if the donation amount is more than, equal to, or less than the target amount, respectively. In the wallet algorithm, the cost of the withdraw function is limited to 0.1 ETH (100,000,000 Gwei), while the other functions are called internally and their gas is added to that related to the calling function. Finally, where there is no internal calling, the tracing mechanism is cost-free. All these characteristics function as view-type responses to an external call that allows a party to inspect all the case details.

As a result of the above-mentioned costs, each transaction's reasonable costs can be determined, which is considered to be the most effective technique for creating a linear relationship between the cost and code complexity. The cost of gas will be higher when using several, more complex types of data (and vice versa), indicating that a higher gas cost may signal that the likelihood is close to the worst case scenario, which is handled using the best practice for solidity coding.

5. Evaluation and discussion

An effective donation traceability system should enhance the collection and handling of information and also promote the exchange of that information among all the involved parties, such as donors, trustees, and needy parties. The proposed framework enables the authentication of the involved parties' identities as well as the tracing of charity donations from the opening of a case through to its completion. Importantly, all the involved parties can participate in tracing the donation-related information.

To evaluate the performance of the proposed framework, a hybrid qualitative approach based on 1) assessing the suitability of the blockchain framework 2) assessing the traceability system was used, as described by Feng et al. (2020), this allowed us to

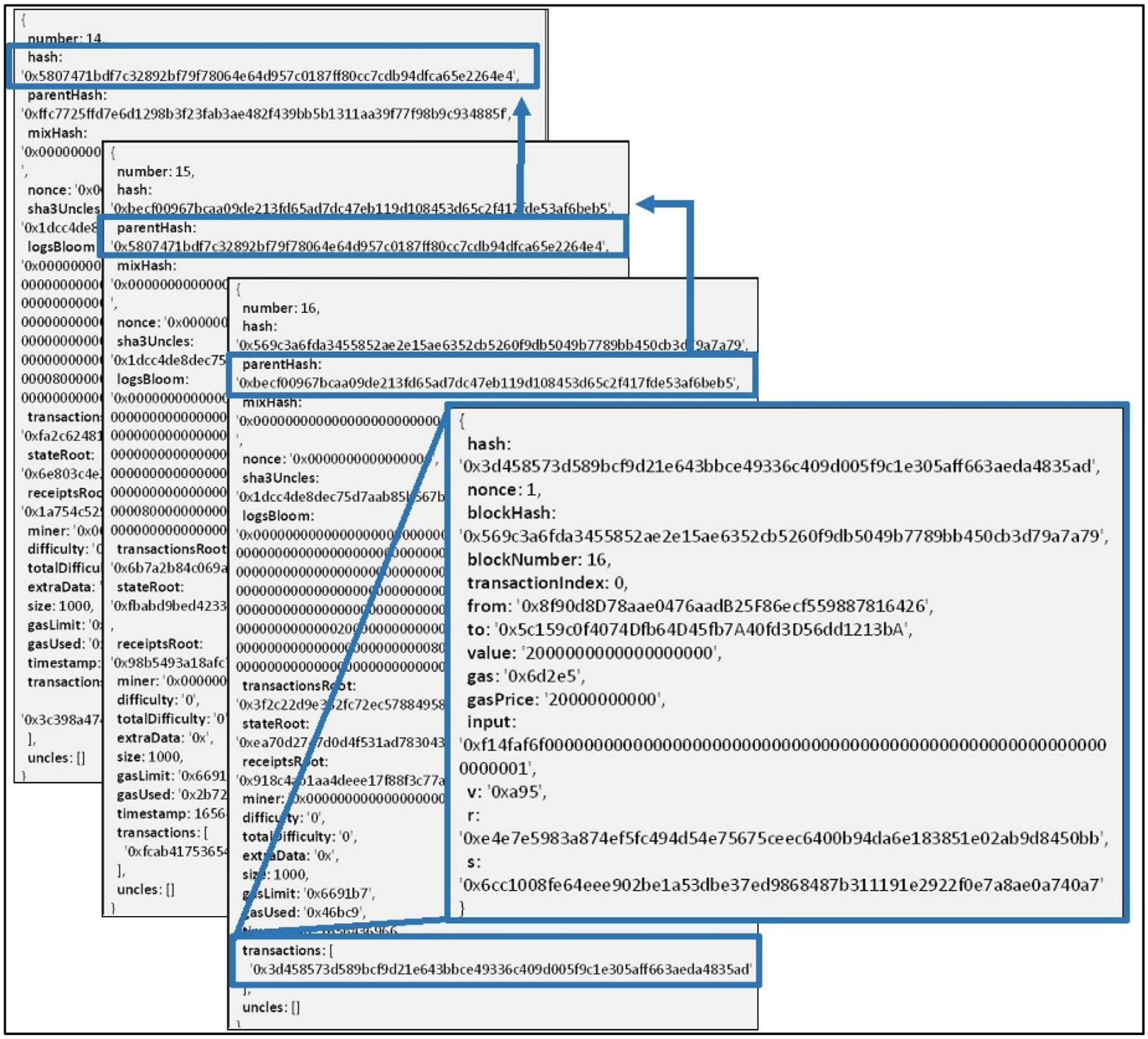

Fig. 9. The i-th block in the system.

evaluate the traceability system based on many criteria in order to validate and improve the entire traceability process.

The suitability of the blockchain framework was assessed, as described by Wüst and Gervais (2018) and Emmadi et al. (2018) based on multiple factors designed to assess the suitability of the technique in terms of meeting the needs of the charity sector. The factors address mistrust between different parties who collaborate and have to change state, where all these parties must be known and trusted. The factors also address whether a trusted third party is needed to determine an appropriate solution for tracing charity donations.

To illustrate the proposed framework, a test of all the system functionalities was performed by joining different parties. A party is able to use the system's functionalities if their address is included among the authorized addresses (Emmadi et al., 2018); otherwise, the party must apply to join the system and be authorized.

To store a case in the blockchain structure, a needy party or trustee must first add the case information using the interface for creating a case. As a consequence, the blockchain initiates a new transaction and records the incoming information in the final block in the chain. A needy party's case must be evaluated by a trustee as either approved or rejected. Once a trustee approves a case, they will then evaluate its importance (i.e., medium, high, or critical) and determine the amount required.

With regard to the cases themselves, each case has a unique ID. Based on this ID, the case information is stored in the blockchain network. Different test cases were created, each with a different status (i.e., processing, uncompleted, completed, or rejected). The processing status indicates that a case still needs to be evaluated by a trustee. The system presents all the approved cases. Several donations may contribute to the closing of a given case. For example, Case 1 received two donations from two different donors. After the first donation, the case remained uncompleted, whereas after the second donation, it was completed. If a case is closed, the system will notify all the involved donors.

Following each execution, a new transaction is recorded in the blockchain. Each transaction and each block have a unique hash value stored in the blockchain. Each block in the chain comprises the block hash, previous hash, value, timestamps, transaction input, sender and receiver addresses, transaction hash, and gas used. Moreover, each block's header information is encrypted using an SHA-256 hash function. Information such as this shows how each block is linked to the previous and subsequent blocks (Casino et al., 2019; Haque and Rahman, 2020). In addition, the hash value preserves the sequence of the blocks and allows for the detection of any manipulation that may be attempted in the chain of charity donations (Nguyen and Kim, 2018).

Furthermore, a new block will be added to the chain for each new party who joins, and all the parties will be provided with an identical copy of the distributed ledger (Ølnes et al., 2017). Thus, the parties can trace all the subsequent transactions on the blockchain by accessing the shared ledger and viewing the progress of the cases along with the timestamps. This ensures the secure traceability of charity donations, which should enhance the parties' trust in the system. Indeed, all the charity donation transactions within the BBDT system are fully traceable (Casino et al., 2019; Haque and Rahman, 2020). Additionally, each donor can view all the previous donations in each case. Fig. 8 presents the i-th block, which shows the transactions and block data as they occur.

With regard to assessing the traceability system, Feng et al. (2020) provided two performance dimensions for evaluating such a system, namely technical and system performance. Various criteria are used to measure the relevance of each dimension, which reflects the system performance.

5.1. Technical performance evaluation

5.1.1. Trusted authority

Traditionally, a trusted authority serves as a central entity that manages and executes transactions. By contrast, blockchain distributes the ledger and the related trust among all the involved parties. This is sometimes referred to as "distributed trust," which indicates that the framework enhances trust through moving away from a central trust model under a given authority and toward a decentralized trust model based on smart contracts and the inherent features of blockchain technology (Alexandris et al., 2018). This implies that the parties involved in a blockchain transaction need not fear that the other parties will engage in wrongful activities (Hu and Li, 2020), particularly when their identity is guaranteed, as it is in the present framework.

5.1.2. Data transparency

The added value of the proposed traceability framework lies in enabling all the involved parties to share the ledger and smart contracts so as to impose policies and constraints among them (Ølnes et al., 2017). It also enables the recording of all the transactions identically at multiple locations. Furthermore, all the parties can see the details of the transactions stamped with the date and time (Nakamoto, 2008), which provides full transparency. This helps to avoid any uncertainties stemming from tampering or cyberattacks, which assists in both the fight against fraud and the automation of agreements (Centobelli et al., 2021). The proposed framework also reduces donors' suspicions regarding NPOs and increases the integrity of charity-donation processes.

5.1.3. Data integrity

The BBDT framework makes use of blockchain technology, which is decentralized, open, anonymous, tamper-proof, and therefore, capable of maintaining the integrity of the charity. As a result, when a donor donates a certain amount, that amount cannot be changed, manipulated, or forged. Any attempts at tampering will be discovered through the mismatched ledgers between different nodes, indicating that the accuracy and consistency of charity data will be preserved.

5.1.4. Immutability

The other key benefit of using blockchain in the BBDT system is the immutability feature, which prevents any changes to or reversal of transactions, as each chain of blocks is permanently stored in all the parties' locations. Any attempt to change a transaction will quickly be identified as an attack (Nakamoto, 2008). This immutability feature also generates trust, as it is very difficult to tamper with the blocks (Alexandris et al., 2018). As a consequence, all the parties can be assured of the authenticity of both previous and current charity donation processes.

5.2. System performance evaluation

5.2.1. Dependability

Blockchain technology is associated with a high degree of dependability, which ensures the system's reliability and availability by providing identical copies of the distributed ledger among multiple parties. Moreover, corrupting one part of the system will not affect other parts. The use of blockchain technology also contributes to increasing the trustworthiness of the charity donation process because all the involved parties have the ability to determine the data source.

5.2.2. Risk reduction

A charity donation system that does not utilize blockchain technology requires a large number of manual inspections and transactions. By contrast, the proposed system reduces the need for human intervention, in addition to removing the need to depend on a third party to verify that the terms of a given contract have been met. For example, as soon as a trustee has accepted a case, the needy party can receive a donation. Thus, two implicit benefits of the proposed system are risk reduction and audibility, which enable the inspection of each transaction, if required.

5.2.3. Stability, and scalability

Stability and scalability are two important features when it comes building a blockchain-based system due to ensuring a stable communication process among the parties. Additionally, the system must be able to include growing numbers of peers and nodes as required to accommodate an increasing number of trustees, needy parties, and donors. The proposed traceability system is stable and associated with good scalability, although increasing the size of the system dramatically may give rise to some unexpected challenges. In light of this, the scalability of blockchain-based charity donation systems represents a promising research area for future studies.

5.2.4. Flexibility and resilience

The proposed framework works as a decentralized network; therefore, it does not involve a single point of failure. It also has the ability to recover quickly from any problems because the remaining nodes will be able to handle operations until the failed node recovers. Furthermore, the system may be able to corroborate and integrate with other technologies without any obstacles, thereby increasing its flexibility and fault tolerance.

5.2.5. Efficiency

The proposed framework allows for the timely and automatic updating of case information in real time, which increases the efficiency and effectiveness of the donation process. It also removes the possibility of hidden costs, accelerates process automation, and reduces the need for paperwork due to reducing the duplication of information and questions (Centobelli et al., 2021; Chang et al., 2019). In summary, the charity donation traceability framework achieves both the synchronization of the traceability information and a reduction in the resources required to complete the process, thereby increasing the system efficiency.

The SQuaRE model is also used in the evaluation of system quality. It is international standards: ISO/IEC 25010:2011—Systems and software engineering—Systems and software Quality Requirements and Evaluation (SQuaRE)—System and software quality models. The ISO/IEC 25010 requirement standard focuses on

Table 3
Comparison between the BBDT framework and other charity donation systems.

	Advantages	Disadvantages
BBDT framework	• Traces the movement of donations from donors to those in need • High transparency allows all transactions to be recorded uniformly across many locations • Ensures data integrity between various nodes • Speeds up multi-step tracing procedures that need numerous steps to just a few minutes • Transfers funds in a secure manner that prevents appropriation • Provides complete protection of all parties' privacy • Includes all significant players in the charity's processes within a single range	• Adoption of the framework, based on its current perspective, may suit medium to large enterprises, although it may add high costs to small enterprises • Consumes high energy and costs due to mining operations • Occupies a sizable amount of hard drive space • Concerns over people's ability to adopt modern technology
Other donation systems	• Serve organizations of various sizes • Easy to use and adopt • Accelerate the storage of transactions as a result of being freed from the mining process • Take up only a minimal amount of hard drive space • Offer significant value for an organization at a more reasonable price	• Modifiable and manipulable transactions can result in the commission of fraud • Real-time transaction traceability is not supported. • Fail easily due to their centralized nature

measuring two items, that is, quality in use and product quality. Quality in use assesses the outcomes of human interactions with the system. By contrast, product quality assesses the static and dynamic properties of the system. The traceability system provides value to its various parties and achieves the items and sub-items of the ISO/IEC 25010 quality evaluation system. Overall, the system has clearly shown that blockchain is useful for building charity donation systems because it increases transparency and provides a secure and trustworthy environment. Table 3 presents a summary of the comparison between the advantages and disadvantages of the BBDT framework and other charity donation systems.

6. Conclusions

Blockchain-based traceability solutions have been shown to offer great utility within the charity sector. Nevertheless, to date, the charity sector in general and NPOs in particular have generally been overlooked with regard to the adoption of blockchain technology (Casino et al., 2019), even though the charity sector is no less important than the healthcare or supply chain sectors. While some relevant studies can be found in the literature, real-world implementations of blockchain traceability solutions remain rare (Botene et al., 2021).

This study has proposed a framework for implementing a blockchain-based charity donation system designed to enable the traceability and transparency of the charity donation process. In addition, a web-based system has been implemented based on the proposed framework to test its applicability and efficiency. Several positive features of the proposed system have been successfully implemented, such as the ability to create a case, accept or reject a case, donate, receive a notification, and trace donations. During the design and development of the system, many tools and software were utilized to connect the off-chain components to the on-chain components in order to structure the final system. The actual system developed featured easy-to-use navigation portals and interfaces, and it was able to authenticate parties who wished to use it. In addition, the privacy and anonymity of all the parties were preserved using a security solution designed to prevent reentrancy attacks. Many test cases were executed in an effort to evaluate the proposed system, which indicated that it was efficient in allowing the traceability of charity donations.

Overall, the findings of this study demonstrate blockchain to be a suitable technology for use in the charity sector, where it can be adopted to replace traditional traceability methods that fail to meet the involved parties' requirements or address the prevailing problems of centralized operation (Casino et al., 2019). The proposed framework facilitates the tracing of charity donations in real time until they are received by the intended recipients through a secure and trustworthy environment that utilizes immutable transactions to ensure the integrity of the charity donation process. It also enables all the parties to be incorporated in a decentralized manner so that they can contribute to creating and donating to charity projects. Moreover, the framework provides visibility and meets the parties' requirements with regard to transparency and security. All charity donations are processed in a high-transparency environment, and coupled with the ability to trace the donations in real time, this enhances all the parties' trust in the charity donation process.

Although research concerning the implementation of blockchain technology in the charity sector remains in its infancy, the technology's prevalence and impact are expected to be substantial in the coming years. The proposed framework should serve as a solid basis for further research in this regard. Furthermore, we expect that the difficulty associated with ensuring the standardization of evaluations based on different types of blockchains will be resolved in the future. This is important because the structure of blockchain, the variations in its types (i.e., public, private, or consortium), and the techniques used in relation to it currently make it difficult to compare different systems with each other. Thus, achieving performance standardization in the charity sector may represent an important step in terms of facilitating the assessment of different blockchain systems in the sector. Such advancements should guarantee the quality of blockchain systems in the charity sector as well as the ability to adapt this technology to a production environment with a focus on the enormous energy consumption side (Ghosh and Das, 2019) to cover all aspects of adopting blockchain systems in the charity sector.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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