Building blocks of a Blockchain-enabled framework for the humanitarian supply chain

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Building blocks of a Blockchain-enabled framework for the humanitarian supply chain

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ABSTRACT

Humanitarian supply chains (HSCs) face significant operational challenges, particularly around trust, transparency, and coordination. Blockchain technology (BCT), with its decentralised and immutable characteristics, offers a promising solution. However, humanitarian organisations often lack a structured framework to guide its implementation. This paper addresses this gap by designing a blockchain-enabled framework specifically tailored to HSCs. A mixed-method approach, using an explanatory sequential design, is adopted. The research begins with a quantitative phase, conducting a feasibility study through a survey targeting key humanitarian stakeholders in Kenya to identify operational needs that BCT could address. Survey data is analysed using SPSS 26.0, and the findings, complemented by secondary literature, inform the development of the proposed framework. The subsequent qualitative phase involves validating the framework through in-depth interviews with humanitarian experts in Kenya. These interviews are coded and thematically analysed using NVivo software. The methodology ensures a high level of research rigour aligned with the study's aim and objectives. The proposed blockchain-enabled framework consists of nine building blocks structured across five phases, from initial planning to full deployment and maturity. Raising awareness is highlighted as the most critical phase for successful implementation. Additionally, the framework emphasises the need for continuous improvement based on user feedback and technological advancements. By addressing key operational challenges, BCT can significantly enhance transparency, integrity, and disaster resilience within Kenya's HSC context.

1. Introduction

Disasters are projected to continue rising and their impacts will raise more economic and human losses due to increased levels of vulnerabilities and exposure by populations that lack coping and adaptive mechanisms to deal with the disaster risks [60]. Humanitarian organisations (HOs), the government, and donors are directly involved in disaster relief operations (DROs). These stakeholders must coordinate at all disaster phases with all other actors, directly or indirectly involved with disaster activities, for improved disaster relief performance [28]. When these actors are coordinating, they form a supply (SC), which is a network of suppliers and buyers involved in upstream and downstream activities [22], only that in this case, a humanitarian supply chain (HSC) network is formed, and the disaster-affected people replace the buyers or consumers in a commercial SC, and the donors form part of the suppliers who offer humanitarian support [28].

HSCs face increased donor pressure to be transparent and accountable, often referred to as 'donor preoccupation', where donors fail to invest in logistical preparations but fund the aftermath of a disaster, which inhibits DRO efficiency as HOs are pushed upwards to meet donor expectations, they neglect the needs of the affected populations [61]. Fraud and corruption in HSCs impede the humanitarian goal of alleviating the suffering of those in need [18,58], which, as a result, pushes the affected persons into poverty. Based on these challenges, there is an urgent need to overcome these barriers to improve HSC performance. Technological innovations could help in the better management of HSCs [27,39]. Particularly, disruptive technologies such as Blockchain Technology (BCT) have received great attention recently to solve the challenges of transparency, traceability, and accountability in numerous industries [34,45,62].

Integrating BCT in HSCs has been reported to solve specific challenges of trust, transparency and accountability, fraud and corruption, and coordination [46,54]. Despite the widely recognised benefits of the blockchain in HSCs, its practical implementation is few [58], and this little empirical evidence limits its scalability [18], as without numerous real-world evidences, it is difficult to validate BCT impacts on HSCs [3].

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Additionally, the big question of how BCT can be implemented in HSCs still remains [52]. This paper aimed to fill this gap by designing and developing a Blockchain-enabled Framework for the HSC, with a particular focus on the Kenya HSC. Mangla and Luthra [39] note that creating awareness about technological advancements in emerging economies is paramount in creating an efficient and responsive HSC.

The empirical validation of the blockchain-enabled framework in Kenya will contribute valuable evidence-based insights for BCT and HSC studies. Baudoin and Wolde-Georgis [5] note that disaster research in the Horn of Africa (HoA) has received extraordinarily little attention, yet the lessons learnt from these countries that are classified as the world's most vulnerable, could largely contribute to global knowledge on disaster risk management (DRM). This research aims to make a notable contribution to the scant research on BCT in HSCs, specifically within developing economies. This research is thus timely and relevant, and the absence of similar work underscores its originality and novelty. This paper will achieve the highlighted aim by addressing the research questions (RQs):

1) To what extent can BCT address operational challenges in Kenya's HSC?
2) What are the key stages HOs should follow to successfully adopt and implement BCT?

2. Literature review

2.1. Blockchain technology

A blockchain is a chain of encrypted data blocks [22] where every block is created to record transactions [16]. New transactions in the form of any token of value or shared data value, such as financial payments and non-financial transactions like intellectual property, are added to the previous transactions, and this forms a chain of blocks [38], thus making it impossible to tamper with the data stored in the chain due to the replication of the data in the blocks across multiple connected computers (nodes) [12]. The automatic distribution of the blocks of information across all network nodes ensures that all users have the updated information, and thus, the database eliminates the disadvantage of a centralised system as it creates no single point of failure [65].

2.1.1. Types of Blockchain architecture

Questions arising from who can run a node in the BCT network, and who need to control what network participants do, form a basic understanding of the types of BCT architecture [70]. Table 1 summarises these types.

A public blockchain is open to anyone who wants to run a node with the choice of doing so anonymously. Public blockchains are more transparent and secure as they consist of many active nodes as compared to the private blockchains [33]. All participants in a Permissionless network can perform all tasks such as authenticating transactions, reading, and writing data. Public blockchains are thus viewed as decentralised networks [37]. Private blockchains allow only members of a particular entity to run the node [51]. In a permissioned network, reading and access duties are limited to authorised persons only. Private blockchains have a central authority that is responsible for finding consensus and it is thus viewed as a centralised network. Consortium blockchains combine both attributes of the private and public blockchains [33]. Duties are segregated. Some nodes may read or write; others may do both, besides other administrative privileges. This means that decision-making nodes are allowed to reach consensus by adding new blocks, while the reading nodes are only allowed to review the ledger [51]. These features often make them be viewed as partially centralised.

Table 1
Types of Blockchains Architecture: Adapted from [33].

Characteristics	Public blockchain	Private blockchain	Consortium blockchain
Network Type	Decentralised	Centralised	Partially centralised
Read Permission	All nodes	Only authorised nodes	Only authorised nodes
Participating Permission	Permissionless	Permissioned	Permissioned
Consensus mechanism	All nodes	Central Authority	Selected nodes only
Efficiency	Low	High	High
Immutability (Tamper-ability)	Nearly Impossible	Possible	Possible

2.2. Blockchain and humanitarian supply chains

There are many motives behind the application of BCT in HSCs. These include improved collaborations among all HSC players and cross-sector partnerships [17], improved trust, transparency, and traceability as all transactions across the network will be visible to all nodes [58], improved accountability to donors for efficient use of resources, and enhanced security due to the immutability of the records stored in a blockchain database [52]. Other drivers include the potential to reduce administrative costs and save time by eliminating middlemen and lowering the risks of disputes by preventing fraud across the network [41]. BCT enhances automation and auditability by eliminating manual processes, particularly in transactions facilitated through smart contracts [29]. Despite these benefits, BCT face challenges related to data privacy, ownership and security; funding issues for testing and implementing the technology; Scalability and sustainability issues; and governance risks arising from disagreements among members of the network [3,57].

3. Research methodology

Fig. 1 represents the research methodology utilised in this paper, covering the research philosophy, approach, strategy, design and the processes involved in developing, validating and fine-tuning the proposed BCT framework.

3.1. Research philosophy

This research adopted the pragmatism research philosophy, which focuses on problems and relevance of RQs and emphasises offering a practical solution to research [32]. The practical solution is a roadmap that will guide key HSC stakeholders in investing in BCT. Moreover, the pragmatism philosophy involves the use of both quantitative and qualitative data collection methods [15], which were adopted in this study.

3.2. Research approach

This research adopted an abductive approach as both deductive and inductive approaches were used for different research questions [64]. Abduction, which is primarily grounded on pragmatism philosophy, aims to generate plausible explanations from empirical data, and identify patterns that can inform and further develop existing theories [11]. In this paper, abduction was used to gather patterns from the quantitative survey to generate plausible explanations for their existence, and to refine and adjusts the explanations based on expert's interviews. Abductive reasoning also played a crucial role in the integration of both quantitative and qualitative data, and the validation of the blockchain-enabled framework by combining expert's insights and creating explanations that fit the Kenyan context.

3.3. Research strategy

This research focused on a case study, in which the Kenya HSC was

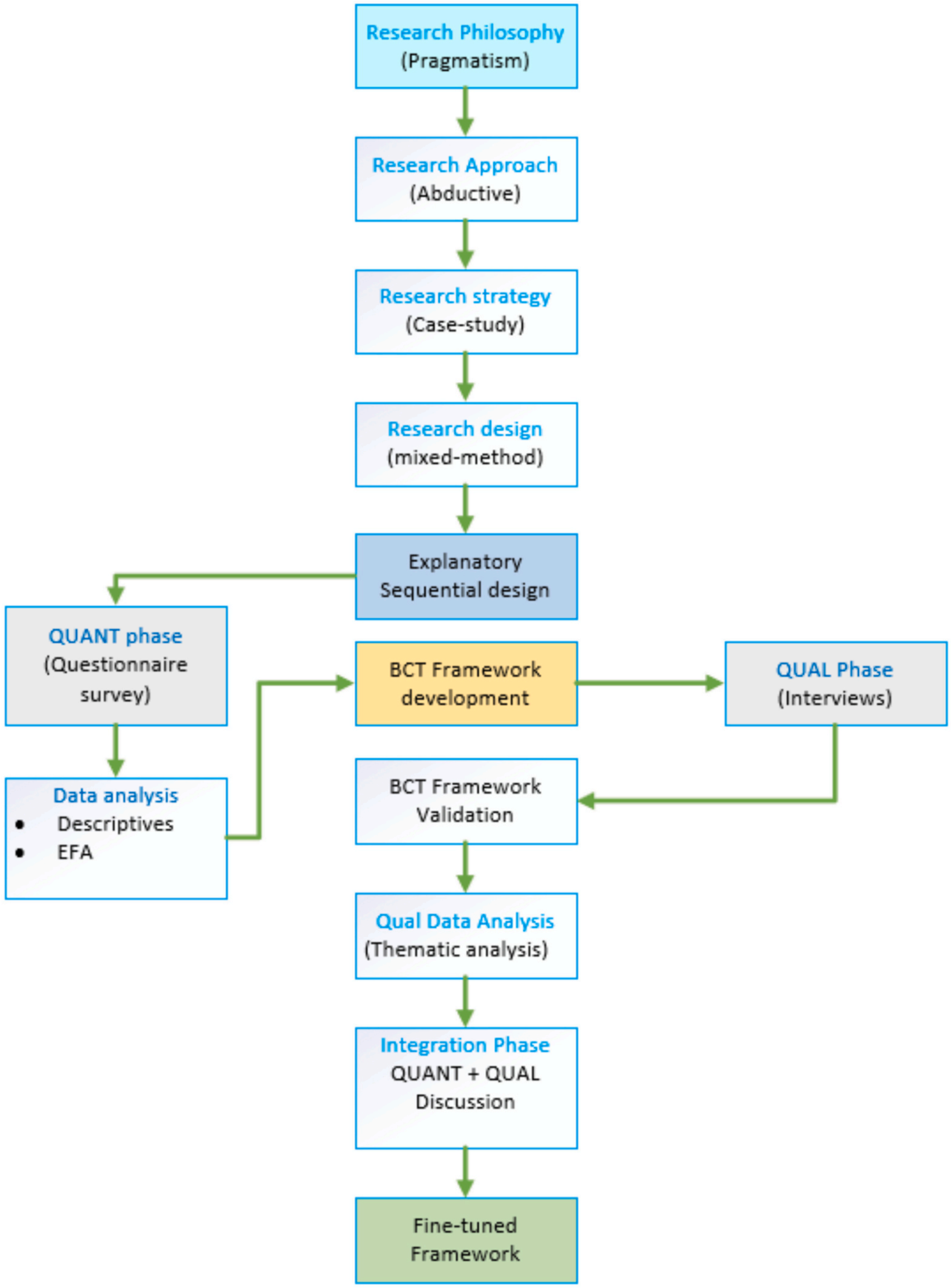

Fig. 1. Research methodology.

studied. Martinsuo and Huemann [40] argued that using case studies to solve specific problems can make a novel contribution to a relevant field. Similarly, authors have recommended the study of context-related cases through qualitative research to build on blockchain studies in HSCs [14]. Recent research recommends exploring blockchain use in different industries and contexts [62] to provide practical insights that can be replicated in other regions and industries.

3.4. Research design

This research used a mixed-method design that combined both explanatory and exploratory approaches. A mixed-method design ensures the collection of both quantitative and qualitative data, thus combining the strengths of both methods [63]. This design is important in complex situations where using a single method may not be sufficient in addressing the research problem [35,47]. This study adopted the explanatory sequential design that starts with a quantitative (QUANT) phase followed by a qualitative (QUAL) phase [68]. A few blockchain studies in SCs have used this research design [2,45].

3.5. Quantitative phase

A survey-based instrument is effective in measuring behavioural constructs despite its challenges with common method bias [44]. This challenge was reduced by designing a questionnaire that could be answered by multiple stakeholders in the Kenya HSC. A pre-test pilot was conducted by HSC professionals in two counties. Pre-tested questionnaires through expert opinions and pilot studies minimise difficulties in answering the questionnaire by respondents, thus increasing data validity and reliability [48]. The target population of this study were the key Kenya HSC stakeholders- the government (both national and county government), non-governmental organisations (NGOs), and development partners. This research adopted the non-probability sampling technique, particularly purposive and snow-balling sampling techniques. Purposive sampling was used to select the most suitable stakeholders to participate in the study. After the selection of the organisations, purposive and snowballing sampling techniques were used to select the most suitable individuals in the selected organisations, to answer the questionnaire [13,50]. The questions were Likert-scale based. (See questionnaire).

In 2022, upon request, the researcher received a list of active NGOs in Kenya from the Kenya NGO Coordination Board. The list had 715 active NGOs operating in Kenya. The researcher used purposive sampling to select only NGOs involved with DRM activities. There were 345 organisations. A sample size of 182 NGOs (calculated using a confidence level of 95 % and a margin error of 0.05) was used [10]. An email was sent to them and six organisations emailed back to say that they were not involved with DRM issues. The researcher also received 66 undelivered email prompts. The researcher went to the NGO's websites that had returned non-delivery messages. Unfortunately, most of the websites were missing, while others had not updated their new addresses. Only two NGOs were contacted via emails using new addresses found. This gives a total of 110 NGOs that received the questionnaire.

Kenya is mostly affected by droughts and floods and populations in the Arid and Semi-arid Lands (ASALs) counties are affected the most. There are 26 ASAL counties and therefore, these counties were targeted purposefully, out of the 47 counties that are operational in Kenya. Most DRM institutions have their headquarters in Nairobi; therefore, a purposive sample to include Nairobi County was conducted. This gives a total of 27 counties. Emails with the researchers' University Introduction letter, and a Qualtrics link to the questionnaire were sent to the DRM offices of these counties. A request to share the questionnaire with employees within the organisation (snowballing), was written in the email. Emails were sent to the UN agencies and development partners like the World Food Programme (WFP). Some HOs personnel, especially those in international NGOs (INGOs) working in Kenya, were contacted via LinkedIn. Some studies in BCT adoptions have used social media networks to target HOs respondents [31].

A total of 116 responses were received from the survey. After excluding 13 responses with missing data, 103 valid responses were analysed using SPSS 26.0. Because the survey targeted organisations for which the number of DRM employees was unknown, the exact number of potential respondents could not be determined, making it difficult to calculate a precise response rate. Nevertheless, the sample size of 103 is considered adequate for survey research, consistent with previous studies recommending a sample size threshold of 100–200 [30,42]. Following the data analysis from the survey, key challenges that existed in the Kenya HSC that could be solved by blockchain solutions were identified. These findings were supplemented with the literature to develop the blockchain-enabled framework.

3.6. Qualitative phase

Semi-structured interviews with key experts from the Kenya HSC, which provide flexibility across interviewees [66], were used to validate the developed blockchain-enabled framework (see the interview guide). The framework was validated by HSC and logistics managers, DRO managers, disaster technical staff, and technology experts. Just like the surveys, purposive sampling and snowballing sampling techniques were used to identify the interview participants as these techniques would ensure the selection of participants with rich information [1]. The challenge of a lack of a large number of BCT experts in HSCs has been acknowledged by prior studies [3,12]. Therefore, the researcher developed introduction briefs prior to the interviews to explain BCT to the interview experts who were sampled due to their DRM involvement and rich knowledge but did not know or know little about blockchain.

Due to practical constraints such as time, cost, distance and security, a convenience sample of seven counties was selected, allowing for timely and feasible data collection [6]. Security concerns have been a major concern inhibiting the collection of data in specific disaster affected regions among researchers [59]. The researchers visited the county government offices, NGOs and development partners present in these counties. These counties were also among the 27 counties that participated in the questionnaire survey. The recommended participants from snowball sampling all had a good knowledge of BCT. The interviews with the snowballed participants were conducted online via Zoom.

To validate the blockchain-enabled framework, participants were asked about its practicality. They were also given an opportunity to improve the BCT-enabled architectural design model. The saturation point was reached at 30 interviews, at the point where further interviews could not benefit in theory building [56]. Two interviews were excluded from the analysis due to insufficient depth and elaboration. For example, when asked about challenges in humanitarian operations, one participant simply responded, "nothing," and when asked about the model, replied, "it's okay." These interviews lasted less than 10 min, well below the scheduled duration of 45–60 min, which accounted for cultural factors such as high-context communication and the need for follow-up prompts. Both excluded interviews were conducted with county government representatives, and neither participant consented to audio recording. As a result, 28 interviews were included in the final data analysis.

Transcriptions of the interviews were made and Nvivo software was used to analyse the data. Thematic analysis ensures that patterns within data are identified, analysed and interpreted [43] The researcher used an inductive approach to code themes as they emerged from the raw data. Sub-categories were developed from the initial codes- indicated by child from parent by Nvivo. Few blockchain studies in SCs have employed similar coding approaches [19,26]. In the write-up, descriptive analysis, which included direct citations from the respondents, was used to support the codes established [48,71]. Reliability of data was achieved by following the ethical considerations in data collection and analysis, getting diverse participants to represent the Kenya HSC, recording the interviews, and providing quotations from the participants on the coded themes [21,43]. Validity was ensured through triangulation with literature reviews and integration with the quantitative study in the first phase.

3.7. Data integration phase

Integration is the stage where mixing quantitative and qualitative data collection or analysis methods occurs, which can be done at the beginning of the study, at an intermediate stage depending on the research design, or at the data interpretation stage [23]. Integration of QUANT + QUAL data was carried out in two stages. First, the partial integration, where the QUANT data was analysed, to get themes and plausible explanations that would form questions for the interview guide, and the full integration of both datasets was achieved when discussing the research findings. The final proposed Blockchain-enabled Framework for the Kenya HSC was refined based on the insights gained from the interviews to ensure that it addressed stakeholder concerns.

3.8. Ethical considerations

This research was approved by the University's ethics committee. A research permit to conduct field work in Kenya was approved by the National Commission for Science, Technology and Innovation (NACOSTI). A participant information sheet that guaranteed participants' confidentiality and anonymity of data, as well as a participant consent form, was given to the interviewees to get their consent to continue with the interview and to record it. An introduction brief of BCT, and the blockchain-enabled framework to be validated were provided during the interviews to all the participants. The questionnaire also ensured that the respondents gave consent to proceed. Confidentiality of participants was maintained throughout the data collection, analysis and write-up. The participants' codes have been anonymised to conceal their identities.

4. Research findings

4.1. Demographic information

Majority of the respondents were from INGOs with 36 respondents as shown in Table 1. 5.8 % of the respondents were in the 'other category'. One respondent from the 'other category' was from a church organisation, while five were from the private sector, with two specifically citing a startup and a telecommunications company, respectively. Most participants were from HOs with more than 200 employees, had an undergraduate degree, and belonged to the age group of 26–33 years as illustrated in Table 2.

4.2. Feasibility study

A feasibility study of the blockchain was performed to assess whether blockchain is needed in the Kenya HSC through a questionnaire among the stakeholders. The items of the feasibility study were adapted from the challenges facing HSCs, which include lack of transparency, trust and traceability, as discussed in various HSC literature [3,57,61]. Other items, such as the difficulties multiple parties face in sharing and reconciling data, were adapted from the blockchain feasibility study by Wang et al. [69], which guides organisations in assessing whether they need to adopt blockchain. Each item and its source are shown in Table 3. SPSS tool was used for data analysis. Reliability of data was checked before running tests on the feasibility study. Cronbach's Alpha was conducted to test the reliability [20] of the 14 items that were measuring BCT feasibility. The alpha value was (0.906), which is greater than (0.7); this means that there was an acceptable internal consistency, and the items consistently measured the same concept of the feasibility of the blockchain [20]. Table 3 illustrates the mean distribution and standard deviation of stakeholder's responses on their experiences when working with other humanitarian partners in Kenya HSC.

Table 2
Demographic information of the respondents.

Parameter	Description	Frequency	Valid Percentage
Organisation type	Local NGO	14	13.6 %
	International NGO	36	35.0 %
	County Government	10	9.7 %
	National Government/ ministry	22	21.4 %
	UN Agency	4	3.9 %
	Development partner	11	10.7 %
	Other (specify)	6	5.8 %
Number of Employees	Less than 50 employees	20	19.4 %
	50–100 employees	15	14.6 %
	100–150 employees	14	13.6 %
	More than 200 employees	54	52.4 %
Education Level	Certificate	3	2.91 %
	Diploma	4	3.88 %
	Undergraduate degree	52	50.49 %
	Postgraduate degree	44	42.72 %
Age	18–25	7	6.80 %
	26–33	48	46.60 %
	34–41	20	19.42 %
	42–49	22	21.36 %
	Above 50	6	5.83 %
N	**103**		

Table 3
Responses of the feasibility study.

Code	Statement	Mean	Std Dev	Rank	Source
F14	Lack of community participation in decision-making	4.27	1.15	1	Developed for this study
F11	Intermediaries' costs and complexity	4.24	1.08	2	[69]
F10	Lack of trust	4.11	1.14	3	[69]
F8	Lack of transparency in compliance and regulation issues	4.08	1.37	4	[58]
F5	Difficulty in shared data reconciliation	4.05	1.25	5	[69]
F6	Data privacy and confidentiality issues	4.04	1.23	6	([3]; [18])
F7	Lack of visibility in coordination	4.02	1.12	7	([54]; [46])
F9	Difficulty in tracking disaster aid supplies	4.02	1.09	7	[57].
F1	Information Reliability Concerns	3.80	1.22	9	[41]
F4	Difficulty in tracking shared data	3.78	1.21	10	[69]
F13	Manipulations and system abuse	3.69	1.32	11	([58]; [18])
F3	Process Inefficiency	3.64	1.33	12	([58]; [18])
F12	Delays caused by transaction dependence	3.23	1.40	13	[69]
F2	Data security and Integrity Concerns	3.18	1.36	14	[3]
	N **= 103**				

Table 3 highlights key challenges in Kenya's HSC, including a lack of trust among partners, concerns about data privacy, coordination, and transparency. Additionally, there were difficulties in reconciling shared data and respondents also viewed intermediaries as adding unnecessary cost and complexity, favouring more community-driven systems. BCT directly addresses these challenges through its core features. First, blockchain's distributed ledger enhances trust and transparency by ensuring that all humanitarian participants access the same immutable records [12]. Second, blockchain cryptographic and encryption features strengthen data privacy and security, thereby mitigating concerns about data manipulation and unauthorised access [17]. Third, blockchain's consensus mechanisms and smart contracts facilitate automation and ease reconciliation of shared data [58], which reduce transaction delay and errors in humanitarian coordination. Finally, blockchain's decentralised structure reduces the need for traditional intermediaries [65], aligning with respondents' preference for community-driven systems while lowering costs and complexity [41]. Overall, both the survey results and existing literature converge to suggest that blockchain adoption can directly mitigate operational challenges within Kenya's HSC.

4.2.1. Exploratory Factor Analysis (EFA)

An EFA aimed at identifying items that could be grouped together to form broader themes [72]. These themes were to be evaluated in the interviews. Several blockchain studies have employed EFA in their data analysis [7,49,53]. For an EFA to be conducted, a sufficient sample size must be used. The usable responses of 103, which is (>50), was sufficient [73]. Besides the feasibility data meeting a sufficient sample size of

Table 4
KMO and Bartlett's Test.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.844
Bartlett's Test of Sphericity	Approx. Chi-Square	822.613
	df	91
	Sig.	0.000

greater than 50, two tests, as shown in Table 4 were done to test whether the data was satisfactory enough to conduct an EFA [7].

KMO Measure of Sampling Adequacy was (**0.844**), and a Bartlett's Test of Sphericity significance was (**0.000**), and since the *P*-values of the tests were **(>0.05)** and **(<0.001),** respectively, the data was satisfactory to conduct an EFA [73]. Each construct in the communalities table that is derived from conducting an EFA, should have a value of **(>0.5)** to be considered sufficient [63]. Using promax rotation, item F14 (community participation) had a factor loading of (<0.5), and therefore, it was removed, and the model ran again. After re-running the model, all the constructs in the communalities table had a factor loading of (>0.5). However, data from the pattern matrix indicated that item 3 (process inefficiency), had a factor loading of (<0.5), and therefore it had to be removed. The model was rerun using 12 items, and these items met the (>0.5) criterion, in both the communalities and pattern matrix table, as shown in Table 5. Three factors were extracted from the EFA as shown in Table 5. These factors had a cumulative variance of 70.84 %, (Factor 1: 48.22 %; Factor 2: 12.91 %; Factor 3: 9.71 %), which indicates that the three factors explain 70 % of the variability in the data [73].

4.2.2. *Grouping of the three extracted factors*

A researcher may label the extracted factors from the EFA, using an inductive approach [73]. The three factors were named based on the characteristics of the grouped items from Table 5.

Factor 1: Operational Transparency.

Items under this category involved issues of a lack of operational transparency and captured the need for BCT to improve these concerns, which would, in turn, lead to improved trust, transparency, data reliability and security, traceability of disaster supplies, and the elimination of intermediaries who add costs and complexity in the Kenya HSC.

Factor 2: Collaborative Privacy.

Items under this category involved issues in coordination in data sharing and reconciliation, while maintaining data privacy. These items captured the need for BCT to streamline data updates and enhance visibility during the coordination of the Kenya HSC stakeholders.

Factor 3: System Integrity.

Items under this category involved current governance systems and captured the need for blockchain to enhance system integrity by eliminating system abuse and manipulations, and minimising latency caused by transaction dependencies, thus ensuring that the Kenya blockchain-enabled HSC system is efficient and self-sustaining.

Table 5
EFA communality and factor loadings.

Code	Feasibility Item	Communality Loadings	% of Variance	Factor 1	Factor 2	Factor 3
F8	Transparency	0.541		0.828		
F9	Tracking aid supplies	0.651		0.747		
F11	Intermediary cost	0.548		0.697		
F2	Data security	0.589		0.659		
F1	Data reliability	0.558		0.599		
F10	Trust	0.657	48.22	0.562		
F5	Data reconciliation	0.713			0.960	
F4	Tracking shared data	0.651			0.733	
F7	Coordination visibility	0.616			0.694	
F6	Data Privacy	0.608	12.91		0.613	
F13	System abuse	0.599				0.865
F12	Dependency delays	0.593	9.71			0.694

5. Development of the proposed Blockchain-enabled framework

The development of the Blockchain-enabled Framework was conducted through literature exploration of industry 4.0 implementation frameworks and blockchain models, and insights from quantitative data analysis. There were no blockchain implementation frameworks in HSCs found in the literature at the time of developing it in this research. Therefore, a benchmark from Blockchain adoption models [69] and Industry 4.0 Implementation Framework [25] was conducted. Industry 4.0 includes disruptive technologies like BCT and considering its implementation framework provide valuable insights for innovation due to its emphasis on meeting the dynamic needs of the digital economy [67].

Wang et al. [69] provided a blockchain adoption procedure of three stages in which organisations in any industry can use in BCT implementation. These stages include the feasibility study phase, the BCT development stage, and the BCT operation stage. The industry 4.0 Implementation Framework by [25] consisted of six stages of strategy development, design and development, transformation, monitor and control, implementation and operation, and management, planning and organisation. This framework guided the design phase of the proposed blockchain-enabled framework, as it was deemed important for HSC stakeholders to view a concept of how they would interact with the blockchain if it was to be implemented in their organisations. This stage was critical in defining which stakeholder did what and it helped in determining the most suitable blockchain platform to use. Baharmand et al. [4] designed a framework for humanitarian blockchain projects while considering humanitarian principles of humanity, neutrality, impartiality, independence, and dignity. The framework was validated from data collected in blockchain projects in Kenya and Jordan, and the applicability of the model was done in Vanuatu. They concluded that infrastructure, end-users, ethics, stakeholders, and privacy are requirements that should be considered in blockchain design contexts, while scalability and intellectual property should be considered in technology and organisation requirements, respectively.

The proposed blockchain-enabled framework for the Kenya HSC consisted of 5 stages as shown in Fig. 2. The stages are also referred to as the building blocks; and they include- *"Conducting a feasibility study/ raising awareness"*; *"Conceptual design of the proposed BCT architecture"; "Critical dimensions for blockchain acceptance and readiness assessment models"; "Implementation" and "Performance measurement"*.

A feasibility study helps to identify why BCT is needed, or to create awareness of the technology in situations where requirements are known [69]. QUANT results showed that BCT in Kenya was needed to solve the challenges of operational transparency, collaborative privacy and system integrity issues. The conceptual design of blockchain-enabled architectural model could help stakeholders visualise how blockchain will be used in HSC operations. For instance, BCT can aid in transparent cash transfers to disaster affected populations, and collaboration with partners during disasters. The design stage also involves making decisions on the BCT platform to use, and governance rules on the consensus mechanisms to adopt [33].

Under the third stage of the critical dimensions for BCT acceptance and assessment readiness, HSC stakeholders should assess their readiness to adopt BCT. Technology acceptance models and maturity models are used to identify the extent to which stakeholders are ready to adopt the blockchain [37]. From the literature, blockchain maturity models are scarce. The maturity model for any industry [69], and blockchain maturity model in the agricultural SC [55] provide five assessment levels ranging from initial/ignoring, which is the chaotic and ad hoc status of the blockchain, to optimising/integrating, which is the continuous improvement of the blockchain. Ronaghi [55] provided nine dimensions of assessment; – Strategy, governance, leadership, culture, people, customers, operations, products, and technology.

After conducting the readiness assessments, Kenya HSC stakeholders will plan the changes they need to develop based on the assessment

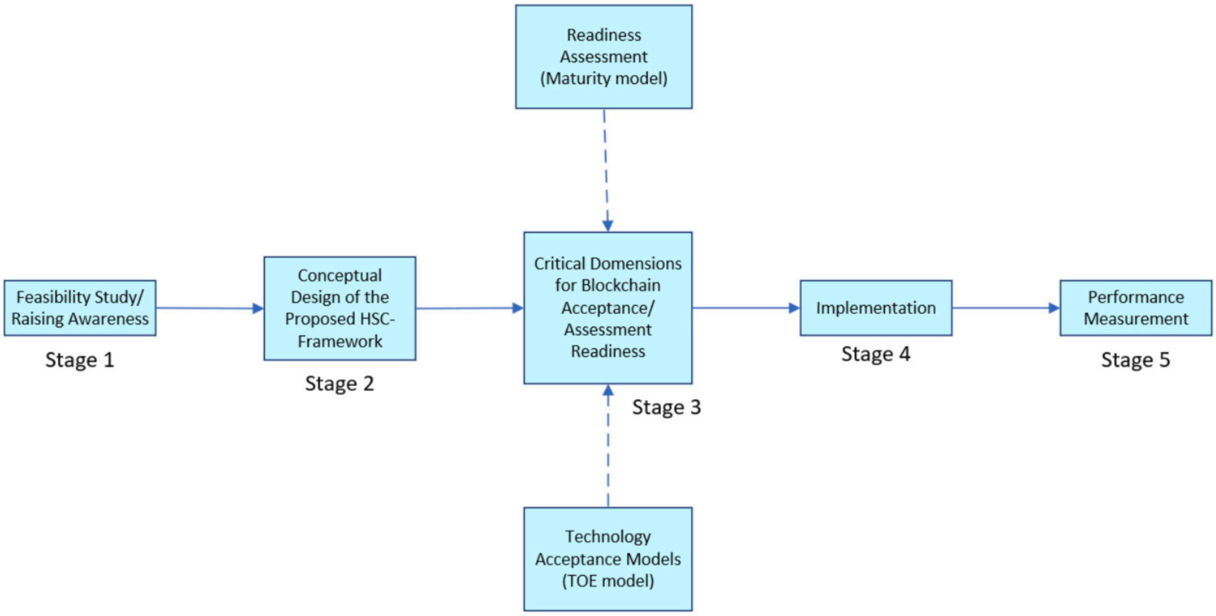

Fig. 2. Proposed Blockchain-enabled Framework for the HSC in Kenya.

criteria such as strategy, leadership, governance, culture, technology, and resources to successfully implement the blockchain. After BCT implementation, HOs will need to maintain their blockchain-enabled systems, establish performance metrics for their evaluation, and improve the BCT-enabled system continuously to enhance sustainability.

6. Interview validations of quantitative data

Respondents were asked about the themes drawn from the EFA Quant Phase. The data analysis suggests that BCT could solve the challenges identified in the feasibility study as there is a lack of trust and transparency, lack of visibility during coordination due to a lack of information sharing and commitment among partners. Participants mentioned that their HOs protect beneficiary data by ensuring that systems are secure and can only be accessed by authorised persons. Some participants, however, mentioned the need to strengthen system integrity and security to prevent potential manipulation. The transcripts are illustrated in Table 6.

Table 6
Transcripts of EFA themes.

Theme	Transcript
Operational Transparency	"*First is lack of commitment from partners. There is lack of trust from partners too. They won't disclose how much resources they have used, they may give a vague figure like 2 M- but will say they don't know the activities.*" Participant, 21NG. "*We do activity-based funding, and when we are monitoring on other partners, they hide programs because they had not started, therefore there is issues of transparency and accountability and avoiding audits and we would like to know- how much did you use? How did you spend it as you sourced it for our people. There is manipulation of distribution ledgers. How do we remove intermediaries? We don't need them! Let's be direct to 'Wanjiku' (the commoners) and not to get half while they were meant to get full.*" Participant, 21NG.
Collaborative Privacy	"*We have an overlap. Certain NGOs overlap projects. You know that NGO A has done a project in this location and then you will find again the same influence is also targeting the same, so all the NGO B & A are supporting one community.*" Participant, 4SN. "*You tell them to share with us their resource envelope so that we can plan together and also distribute the interventions across. They may not like fully to reveal what they have. So sometimes you find an area is over concentrated by some agencies and others are left out.*" Participant, 24NG.
System Integrity	"*Beneficiaries are identified and verified through a community-based validation (CBV) process, and we have security protocols for data protection, but again nowadays there are a lot of hacking, and we find that currently the Huduma number (ecitizen identification number) was hacked and there was no information about the hackers.*" Participant, 23NG. "*You know, as organisations, everyone wants a safe space for their information in this era we are generating so much information, loss of information, then the access that is not actually warranted, You heard the other day that our systems, were hacked; the eCitizen. So, I think if we can get safer systems, why not? We need to go to the for them.*" Participant, 5SG.

6.1. Framework validation

To validate the proposed blockchain-enabled framework, participants were asked a series of questions. What are your thoughts on the proposed Blockchain-enabled Framework for the Kenya HSC? Are there any building blocks that are missing or any that are present and need to be removed and why? The data analysis resulted in key thematic areas:

a) Unpacking the main points to include details of each stage for more clarity
b) Remove the feasibility stage and begin with creating awareness
c) Assess readiness before designing the architectural model
d) Add the piloting stage before the implementation
e) Add a training stage
f) Include performance measurement-mid way
g) Insert reverse arrows to incorporate feedback for continuous improvement

Some of the transcripts include:

"Personally, I feel like for the feasibility, I think we are already there because we need it, it is not a secret that we need it. Let's start with creating awareness. Awareness is basically what you need to do, to enlighten on the need to use this technology because it's a good one" Participant, 11JC.

"At the stage where you develop a prototype for the technology, maybe through a simulation exercise (could be the second stage of the conceptual design), after this stage, I feel like you should develop a pilot stage for the same. The pilot also gives you answers or questions for the next stages."

Participant, 12LN.

"For me, rather than making it linear, I would say you don't measure performance at the end. You should come with a conceptual framework where at all these stages you are measuring performance. You can make measuring somewhere in the middle so that it looks like a Vienn so that measuring can count in each stage. So, as a technology, does it have room for improvement? Because where is it? Where does it fit, indicate an arrow on how you now link that feedback to continuous improvement of the technology." Participant, 5SG.

7. Phases of the validated Blockchain-enabled framework

The stages of the refined blockchain-enabled framework were categorised into 5 phases as shown in Table 7. Participants noted that awareness stage was the most critical stage in the framework.

a) **Raising Awareness**

The objective of this stage is to create an understanding of BCT to the Kenya HSC stakeholders, by explaining what it is, how it works, its potential benefits, drivers and drawbacks and the use cases in HSCs. Raising awareness could involve organising workshops and seminars with the multiple stakeholders to address misconceptions about BCT and encourage buy-in. Fig. 3 represents the key activities for the awareness stage. When raising awareness, communication about the value of blockchain in the Kenya HSC should be conducted by breaking down how it could be applied in the four DRM phases of mitigation, preparedness, response, and recovery as illustrated in Fig. 4.

b) **Readiness assessment**

Readiness assessment will help organisations to assess their ability to adopt BCT. The assessment dimensions proposed in this study are shown in Fig. 5 and they include:

a. Strategy – BCT implementation plan
b. Leadership- top management support, change management
c. Governance -Laws, policy limitation, decision-making structures & consensus
d. Social & cultural factors – values from employees and communities; change-user requirement.
e. Technology – infrastructure, tools, skills, digitisation of data
f. Resources – finance, hr, investment, maintenance
g. Vendors- values, expertise, benchmarking cases

The assessment model dimensions range in five maturity levels from initial to integrating as shown in Fig. 6. Further explanations of the maturity levels in each assessment dimension are provided in Table 8.

7.1. Design

The objective of the design stage is to develop the BCT architectural model that incorporates key HSC stakeholders. A consortium blockchain

Table 7
Phases of the validated Blockchain-enabled Framework.

Phase	Associated Stage
Initial phase	Raising Awareness
	Readiness Assessment
Design phase	Design
Development phase	Pilot Testing
	Performance Measurement and Conformance to Requirements
Deployment phase	Physical Implementation
	Training
Maturity phase	System Live
	Maintenance and Continuous Improvement

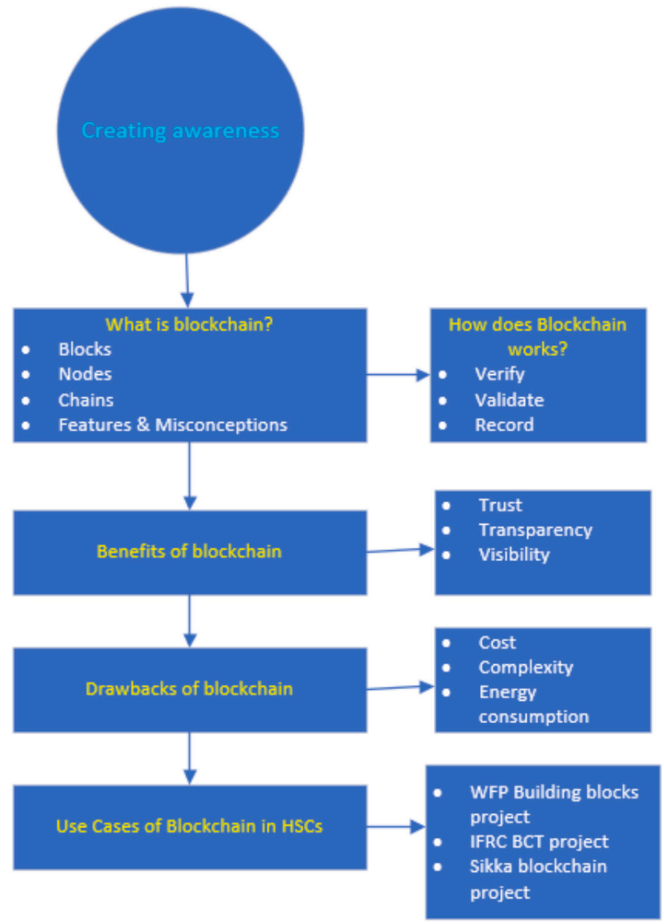

Fig. 3. Awareness criteria.

platform is recommended to combine the benefits of transparency and confidentiality. HOs stakeholders must establish the design principles such as who interacts with them in the blockchain and what roles they will have. Other consideration includes where the data will be stored. Will it be stored on the cloud or in the blockchain? Participants noted that:

a. Key HSC stakeholders like NGOs and all government ministries should be members of the blockchain-enabled architecture, as disaster is a cross-cutting issue.
b. Communities should participate, and incorporation of community feedback should be done to ensure the systems evolve based on users' requirements.
c. The blockchain database should be partitioned based on the information stored, to ensure that the right members interact with it and make it easy to govern it.
d. Blockchain should be designed to integrate climate adaptation

Some of the transcripts include:

"You should also get the feedback mechanism from the community. You should give that allowance in the design such that you're able to get the feedback from the community for improvement and for faster response." Participant, 2SC.

"In the blockchain database, it should allow for partition. We are already talking about climate information, drought information, safety net protection issues, and in my weirdest thinking, you just ought to partition this to ensure a match with the right members and for privacy." Participant, 5SG.

I would also suggest for your proposed blockchain-enabled disaster management structure, let it focus more on risk reduction because also when we talk about climate change, we are looking at incidences of adapting more

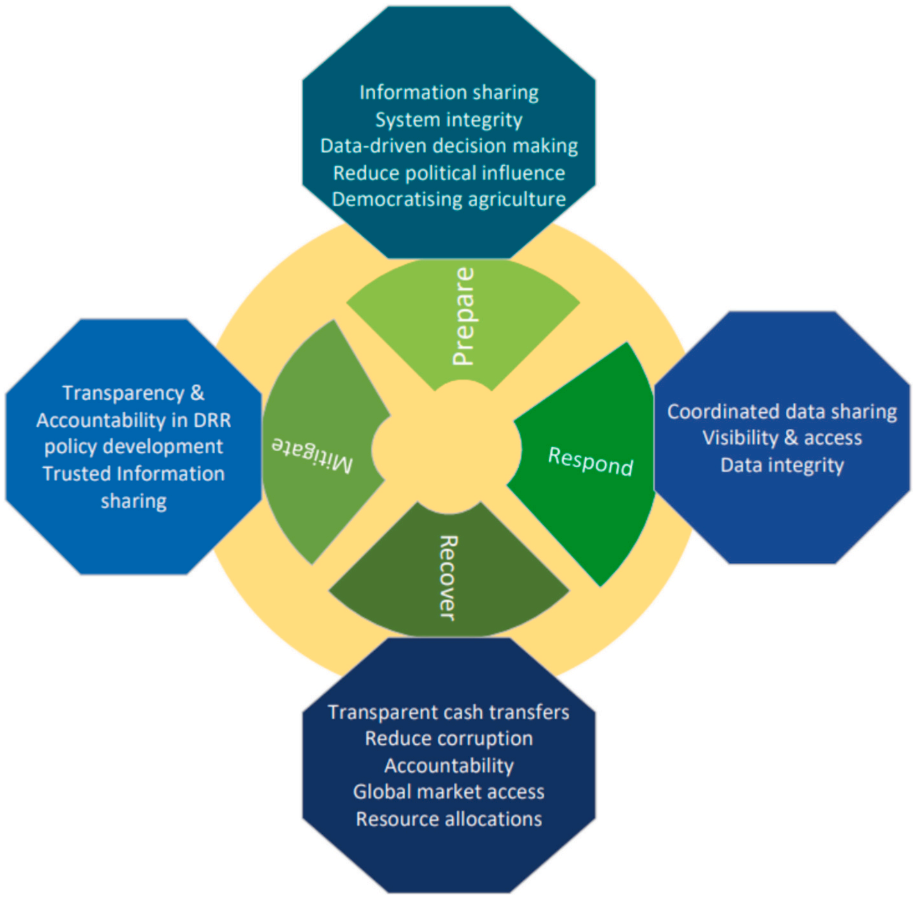

Fig. 4. Blockchain value across the disaster risk management phases in Kenya.

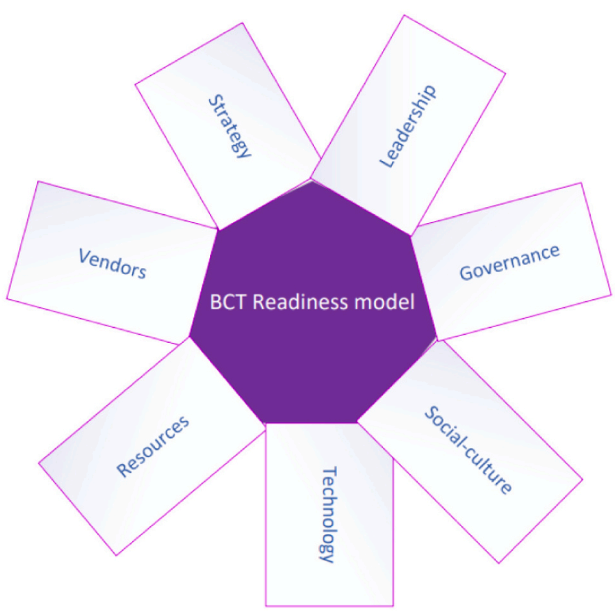

Fig. 5. Blockchain assessment model.

than mitigation." Participant, 2SC.

Fig. 7 illustrates the architectural design model for blockchain-enabled HSC of Kenya, which incorporated the above feedback. The current community-based validation (CBV) process for beneficiary

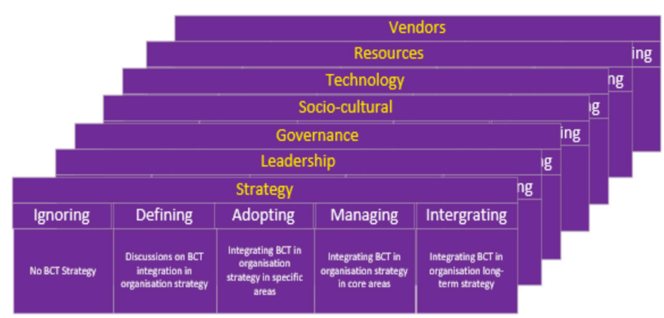

Fig. 6. Maturity model map.

identification in Kenya is sufficient. Biometric information on beneficiaries should be added for easy validation. Smart contracts with predefined protocols should be made with registration of persons departments for validation. The blockchain-validated identities are maintained in the system with agreed rules on how to share such data with other HSC partners.

c) **Pilot Testing**

HOs need to have pilot projects to build momentum towards BCT. The first step could be identifying a specific use case, such as cash transfer, for the pilot project. The pilot project should involve collaboration with a small group of HSC stakeholders. A set of key performance indicators should be established in the pilots. When the pilots become successful, user's attitudes towards BCT could improve.

Table 8
Refined maturity levels for BCT implementation in the Kenya HSC.

Dimension	Maturity Levels				
	Ignoring	Defining	Adopting	Managing	Integrating
Strategy	No BCT strategy	Discussions on how BCT could be integrated in organisation strategy	Integrating BCT into organisation strategy for specific areas only	Integrating BCT into core parts of organisation strategy	Integrating BCT in organisation's long-term strategy
Leadership	No interest in BCT	Exploration of BCT	Support of BCT pilots & small-scale projects	Driving BCT initiatives fully	Driving strategic use of BCT
Governance	No BCT governance structures	Basic governance discussions with no structures in place	Governance structures for managing pilot projects	Governance structures are fully established	Fully integration of BCT governance structures with broad practices
Sociocultural	No openness to BCT	Acceptance of the idea of BCT, with efforts to build community trust	Supporting BCT experimentation internally, with engagements from community members	Usage of BCT in daily operations, with regular communication from communities	Fully embracing BCT, with strong trust and respect for social values and encouraging community feedback
Technology	No exploration of BCT architecture & tools	Explorations of BCT architecture & tools	Basic architecture & infrastructure established for experimentation	Well-developed infrastructure and system integration	Full integration of BCT into organisation's infrastructure
Resources	No BCT resource allocation	Allocations for BCT Exploration	Allocations for BCT pilots, small-scale implementation	Allocations for BCT operational use	Long-term allocations for BCT innovation
Vendors	No interaction with BCT vendors	Exploring on BCT vendors and researching those that aligns with organisation's values	Engagements with BCT vendors on small-scale projects, prioritising those with similar humanitarian values	Establishment of formal partnerships with BCT vendors that share similar humanitarian values	Establishment of long-term agreements with BCT vendors, building relationships based on shared humanitarian values

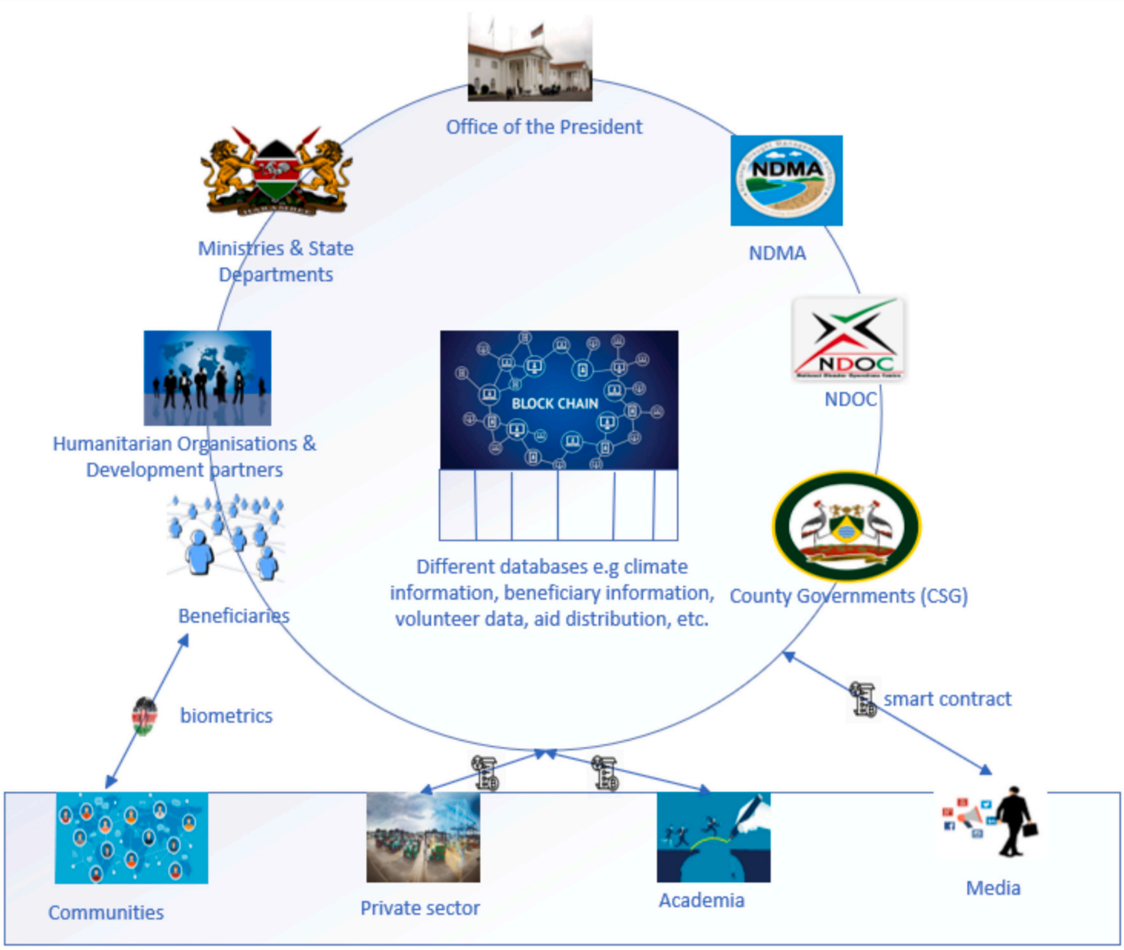

Fig. 7. Validated Design of the Blockchain-enabled architectural model for the Kenya HSC.

d) **Performance Measurement & Conformance to Requirements**

The pilots help in identifying problems before implementing BCT. If the piloted projects conform to Key Performance Indicators (KPI) requirements, then HOs can proceed to the next stage of physical implementation. If there is non-conformance, then issues should be checked in the design phase before repeating the pilot.

e) **Physical implementation**

After successful pilot testing of a specific use case, HOs should roll out the physical implementation of BCT. Full implementation of BCT may take time and hence a BCT implementation plan, which is adequately funded, will ensure a smooth transition.

f) **Training**

In the validated framework, physical implementation and training are done in parallel, as it may take time to fully implement BCT across all HO operations at once. Some organisations may, however, decide to first implement BCT fully in all areas (system live, in the next stage) and then train staff.

g) **System Live**

After the implementation and training of personnel, the BCT-enabled system will be operational, and HOs will begin to get the full benefits of the blockchain.

h) **Maintenance and Continuous Improvement**

HOs should continuously improve the blockchain system, maintaining and upgrading it based on HSC user requirements and technological advancements. Further training on lessons learned will ensure the sustainability of the system.

7.2. *Validated Blockchain-enabled framework for the Kenya HSC*

The fine-tuned framework had nine stages as shown in Fig. 8.

8. Discussions

Blockchain promises to significantly reduce the challenges of operational transparency, collaborative privacy, and system integrity issues within the Kenya HSC, thus providing a pathway to an accountable and sustainable HSC. A key societal issue highlighted in the study is the lack of community participation in HSC decision-making processes, which signals a need for more inclusive and participatory systems. BCT decentralised architecture can empower communities to have a direct voice and influence in humanitarian operations [33]. However, for these societal benefits to be realised, greater attention must be given to the quality of data entered in the BCT system, as inaccurate or manipulated data could undermine the very trust and transparency that BCT aims to enhance [57]. Other issues such as lack of trust and transparency in disaster aid supplies, could be addressed by blockchain's immutability and transparency features [4,17,52].

The development of the Blockchain-enabled Framework was conducted through literature exploration of industry 4.0 implementation frameworks and blockchain models, and insights from quantitative data analysis. Wang et al. [69] blockchain adoption model provided an important foundation for conducting a feasibility study for BCT in Kenya HSC to evaluate the current challenges faced by humanitarian partners that could be solved by the blockchain. The feasibility study from the quantitative phase formed part of the first building block of the

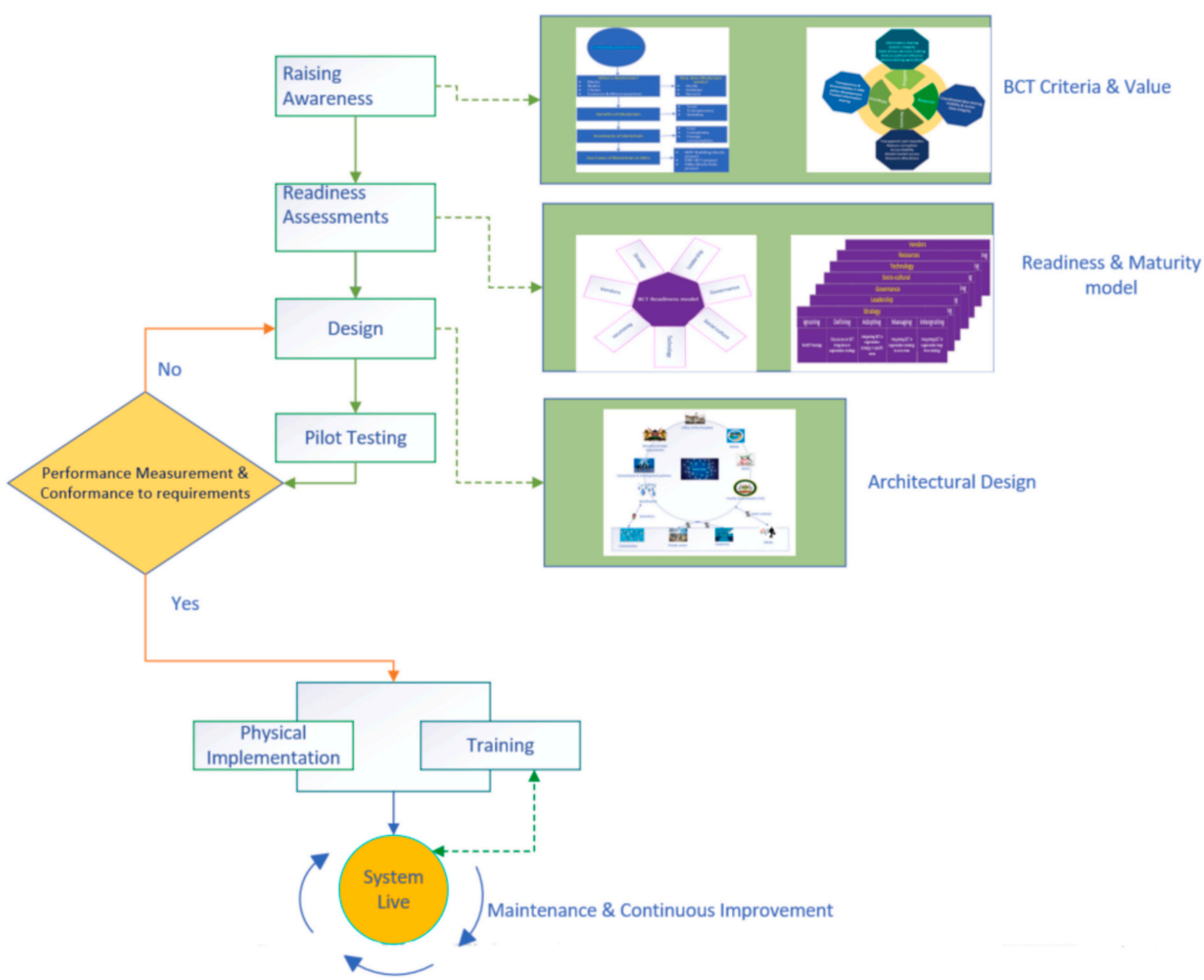

Fig. 8. Building blocks of the validated Blockchain-enabled Framework for the HSC in Kenya.

blockchain-enabled framework. The proposed framework also included an awareness phase, which was missing in [69] model, in cases where HOs had conducted a feasibility study and were already in the process of adopting the blockchain or had already adopted the blockchain. Wang et al. [69] BCT model was also missing the performance measurement stage, and this was included in the proposed blockchain-enabled framework as HOs need to set key performance indicators for BCT implementation and measure its performance over time to ensure sustainability of the system. The performance measurement stage was present in [25] industry 4.0 framework.

The implications of the validations of the Blockchain-enabled Framework for the Kenya HSC are numerous. First, focusing on the awareness stage could promote collaboration in the understanding of the blockchain and reduce resistance to implementing it by the stakeholder's [8]. Piloting should be prioritised to mitigate risks that could be costly before full-scale implementation [24]. Conformance to predefined requirements and incorporation of feedback loops, ensures that errors can be detected and solved early, thus saving costs before the actual implementation. The recommendation of feedback loops also indicates that the blockchain system should evolve based on user experiences [8] and stakeholders' needs, to make it culturally and contextually inclusive, and this adaptivity ensures that the BCT system remains relevant over time. Recommendations on training at the different stages, promotes technical skills and preparedness to use the system [9]. Leung et al. [36] supports that BCT should be taught through a constructivist and pragmatism approach, of using group discussions and simulations, respectively. Data categorisation within the blockchain could lead to quicker access of data by different stakeholders, and security controls can be used to ensure that each stakeholder get access to only the required data, for improved data privacy and security [9]. Finally, the framework highlights the need for cooperation between blockchain developers and HSC practitioners for embedding climate adaptation considerations into the design of humanitarian blockchain systems for long-term environmental sustainability.

The final validated blockchain-enabled architectural model incorporated diverse stakeholders as recommended by the participants, which reflect a shift to designing humanitarian blockchain projects that are decentralised, inclusive and feedback driven, thus promoting humanitarian principles and ethics [4]. Practitioners should conduct thorough readiness assessments before designing the blockchain architecture to ensure that system development is contextually appropriate. Wang et al. [69] maturity model focused on technical maturity of blockchain implementation while Ronaghi [55] maturity model focused on functional capabilities of blockchain across the agricultural sector. The maturity model developed for this study focused on multi-dimensional readiness as blockchain success is not just the technology adoption but also alignment of strategy, leadership, and governance.

Although the study reveals numerous operational challenges within the HSC in Kenya that blockchain could reduce, its implementation should be done carefully and ethically, and not from the perspective of implementing it due to its hyped features [57]. Blockchain should be implemented strategically, considering the cost-benefit analysis derived from adopting it. Where existing systems provide some features such as security, but not other desirable features like transparency, HOs could consider hybrid solutions [26], where the traditional systems are integrated with blockchain features like smart contracts to have both costs and efficiency benefits.

9. Theoretical implications

This study advances theory in three ways. First, it extends blockchain adoption theory within the humanitarian supply chain context by demonstrating that blockchain implementation is not solely a technological decision, but a socio-technical process requiring alignment of organisational strategy, governance, cultural readiness, and inter-organisational collaboration. Existing adoption and maturity models focus predominantly on technical or functional readiness [55,69]. In contrast, this study introduces a multi-dimensional readiness perspective, positioning blockchain adoption as contingent on the interaction between organisational capabilities, stakeholder dynamics, and contextual conditions within humanitarian environments.

Second, the study contributes to HSC theory by framing blockchain not only as a tool for operational efficiency [17,46], but also as a mechanism for enhancing participatory governance and community inclusion in aid decision-making. This broadens theoretical understanding of how digital infrastructures can support accountability, equity, and ethical practice in crisis response.

Third, the validated Blockchain-enabled Framework and corresponding maturity and architectural models provide a theoretically grounded pathway that links feasibility assessment, awareness, piloting, performance measurement, and progressive maturity. These phases articulate how blockchain adoption evolves over time in humanitarian contexts and offer a sequential and adaptable model for future scholarly testing, which is lacking in the literature ([3,18,58]).

10. Contribution to knowledge

This study contributes to knowledge in several ways. Empirically, it is one of the few studies to conduct a feasibility assessment of blockchain adoption within a real-world humanitarian ecosystem, incorporating multiple actors including NGOs, government agencies, development partners, and private sector actors. This ecosystem perspective moves beyond single-organisation blockchain pilots and provides a more comprehensive understanding of inter-organisational dynamics.

Methodologically, the study advances literature by applying an explanatory sequential mixed-methods design, addressing the current gap where many blockchain studies rely either on conceptual theorisation or technical prototypes. The integration of quantitative factor analysis with qualitative validation enhances robustness.

Conceptually, the study contributes a validated Blockchain-enabled Framework, a multi-dimensional maturity model, and a contextually adaptable architectural model. These collectively offer a structured roadmap for blockchain implementation in resource-constrained environments and provide a foundation for future confirmatory, comparative, and policy research.

11. Conclusion

This paper aimed at developing and validating a Blockchain-enabled Framework, which acted as a roadmap to guide the Kenya HSC stakeholders on BCT implementation process. To achieve this aim, a feasibility study was conducted on the operational challenges facing the Kenya HSC that could be addressed by the blockchain. The final validated framework consisted of five phases from initial planning to the maturity phase, along with subsequent models such as a maturity model and architectural model.

BCT has great potential for transforming the humanitarian sector in Kenya, and creating awareness about its potential to HSC stakeholders is critical for its wide-scale acceptance and possible adoption. Blockchain should be adaptable and upgradable to meet changing humanitarian needs, and the evolving nature of blockchain standards. Additionally, cooperation between blockchain designers and developers, and HSC stakeholders is required to develop customisable designs that are user friendly.

This research contributes to the HSC literature by conducting a BCT feasibility study and validating a framework that guides BCT implementation. The study adopted an explanatory sequential design, adding to the limited mixed-methods research in BCT studies in general and in the humanitarian sector. The research contributes to the development of an assessment tool and maturity model to guide HOs in adopting the blockchain across different stages, ranging from ignoring to experts. As new explorations of BCT applications in HSC continue to emerge, most studies focus on stand-alone HOs such as NGOs. This study's contribution is that of using an ecosystem perspective. This diversified view offers a robust solution to complexities in HSCs, implying the need for coordinated efforts to maximise BCT benefits.

12. Limitations and future work

This study faced several limitations that have implications for the interpretation and generalisation of its findings.

12.1. Data access constraints

The study encountered challenges in accessing key informants and organisational data. The limited number of blockchain experts in Kenya and restricted access to some humanitarian organisations, particularly their head offices, constrained the depth of insight available. Although efforts were made through physical visits, email requests, and snowball sampling, several interviews could not be conducted due to security clearance issues or participant unavailability. Future research could address this limitation by employing extended engagement periods, mixed remote and in-person interview strategies, or partnerships with sector networks to improve access.

12.2. Contextual scope

The findings and validation of the Blockchain-enabled Framework were based on stakeholders within the Kenyan HSC. While this context provides a valuable empirical foundation, the framework's generalisability is limited. Future studies should validate and refine the framework across diverse geographical contexts and include a wider range of actors, such as community-based organisations, faith-based organisations, and end-beneficiaries. Additionally, despite the potential benefits of BCT implementation in Kenya's HSC including enhanced transparency and system integrity, its adoption may face significant financial, infrastructural and cultural barriers, which warrant further investigation and solutions.

12.3. Methodological constraints

The exploratory nature of the study meant that factor structures were established through exploratory factor analysis (EFA). To further strengthen validity, subsequent research should apply confirmatory factor analysis (CFA) to test and refine the identified constructs. Additionally, further examination of the blockchain-enabled architectural model is needed to understand its implications for local communities, particularly in the areas of trust, community engagement, and data ownership rights. Finally, based on the participants' feedback regarding the use of the architectural model for climate adaptations in HSCs, future studies should examine the environmental impacts of BCT implementation, particularly in regions vulnerable to climate-related crises.

Despite these limitations, the study provides an empirically grounded and contextually relevant framework for blockchain adoption in the HSC in Kenya. It contributes novel insights into stakeholder perceptions and system design considerations in resource-constrained environments. These findings offer a strong foundation for broader validation and future theoretical and practical development in the field.

CRediT authorship contribution statement

Jemimah Maina: Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Sameh Saad:** Writing – review & editing, Validation, Supervision, Software, Resources, Project administration, Data curation, Conceptualization. **Terrence Perera:** Writing – review & editing, Validation, Supervision, Software, Resources, Conceptualization. **Ramin Bahadori:** Writing – review & editing, Validation, Supervision.

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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Data availability

The authors do not have permission to share data.

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