Education and Information Technologies (2024) 29:323–349
https://doi.org/10.1007/s10639-023-12261-y

Blockchain for energy efficiency training in the construction industry

Yasin Celik[1] · **Irini Barbero**[1] · **Andrei Hodorog**[1] · **Ioan Petri**[1] · **Yacine Rezgui**[1]

Received: 24 November 2022 / Accepted: 4 October 2023 / Published online: 7 November 2023

Abstract

The construction sector faces the urgent need to prioritize energy efficiency due to an increasingly stringent regulatory landscape in response to the climate change agenda. Central to this transition is the pivotal role of education in equipping professionals with the necessary knowledge and skills. Educational solutions have emerged as powerful tools for promoting awareness and interventions to mitigate climate change. This article provides a case study that highlights the successful utilisation of computer technology in delivering digital solutions to advance energy education and promote more informed energy practices in the construction industry. The utilisation of digital technologies can enhance collaborative efforts in energy efficiency training, which is of critical significance in ensuring the security, sovereignty, transparency, immutability, and decentralisation of interventions related to energy education. This paper presents a framework that utilises Blockchain technology to facilitate training labelling and authenticity based on smart contracts and mobile passports to provide a secure and efficient solution for the delivery of training and education in the energy domain. Our research examines the challenges and opportunities related to energy efficiency training within the construction industry. By integrating industry-specific insights, exemplifications, and case studies, we provide an in-depth understanding of the interconnection between energy efficiency education and digital solutions with the unique context of the construction industry. We underscore the importance of leveraging digital platforms as educational tools to foster a deeper understanding and adoption of energy-efficient practices. We demonstrate that educational solutions play a pivotal role in driving awareness and interventions for mitigating climate change, greatly empowering individuals and organizations to adopt energy-efficient practices and to address sustainability objectives.

Keywords Energy efficiency · Energy education · Certification and labeling · Blockchain · Smart contract · Digitalisation · Construction industry

✉ Yasin Celik
celiky@cardiff.ac.uk

[1] BRE Institute of Sustainable Engineering, School of Engineering, Cardiff University, Cardiff, UK

1 Introduction

The construction sector is a prominent actor in the world economy, accounting for around 6% of the global gross domestic product (GDP) and having significant implications on a global scale. In spite of the collaborative efforts now being made worldwide to promote sustainability in the construction sector, there is compelling evidence that these efforts should be amplified urgently to have a genuinely revolutionary impact on the building industry (Alhamami et al., 2020). Several authors Backlund et al. (2012) emphasize the significance of energy education and knowledge showing that education has a significant impact beyond the essential relevance of successful technology.

The integration of digital platforms within the context of education presents various challenges regarding verification (Chiş & Caramihai, 2023), authentication (Almadani et al., 2023), certification (Rustemi et al., 2023), and associated functionalities (Alshahrani et al., 2021). One key challenge is ensuring the security and authenticity of digital credentials, requiring robust mechanisms to prevent fraud and maintain credibility in training and education (Das et al., 2023). Privacy and data security are crucial concerns, necessitating strong measures to protect sensitive student information from unauthorized access (Kumar et al., 2023). Interoperability poses another significant challenge due to the variety of digital platforms used in education, requiring standardized protocols for seamless data exchange (Gilmore et al., 2016). In order to optimise the utilisation of these platforms, it is essential to address the issues related to digital literacy and skills gaps (Ferri et al., 2020). Building trust and credibility in digital education platforms is essential for their widespread acceptance. Overcoming these challenges allows educational institutions to leverage digital platforms for enhanced educational processes and outcomes (Schroeder et al., 2010).

Energy efficiency training has been demonstrated to be a game-changer in the success of the construction projects, contributing to the enhancement of energy efficiency results and objectives (Barker et al., 2009). However, other impediments persist, and the industry's current general environment presents a fragmented picture (Rezgui & Miles, 2011), (Alhamami et al., 2020). Related studies (Barbero et al., 2022), Rezgui & Miles (2011) argue that the most significant energy efficiency barriers identified in the academic literature include, but are not limited to:

- *Reluctance in the face of technical risks or costs of production loss:* Many construction professionals may hesitate to adopt energy-efficient practices due to concerns about potential technical risks and the perceived costs of production loss. Bridging this gap requires targeted education and training programs that address these concerns, providing professionals with the necessary knowledge and skills to mitigate risks effectively.
- *Perceived excessive energy investment:* A common barrier to energy efficiency adoption is the perception of excessive upfront investment. By educating stakeholders about the long-term financial benefits and return on investment associated with energy-efficient technologies, such as reduced operating costs and increased property value, the perceived burden of energy investment can be overcome.
- *Preference for alternative capital investments:* Construction projects often face competing demands for limited financial resources, leading to a preference for

alternative capital investments over energy efficiency initiatives. Integrating education that emphasizes the long-term advantages of energy efficiency, such as improved sustainability and reduced operational expenses, can help decision-makers recognize the value and prioritize energy efficiency within project budgets.

- *Uncertainty about the evolution of energy prices:* Fluctuating energy prices can create uncertainty for construction professionals, impacting their willingness to invest in energy-efficient solutions. Education programs should address this concern by providing insights into energy market dynamics, forecasting trends, and showcasing the resilience of energy-efficient measures in mitigating cost volatility.
- *Lack of experience with technology:* Many professionals may lack familiarity or hands-on experience with energy-efficient technologies. Incorporating training initiatives that offer practical exposure to these technologies, coupled with real-world case studies demonstrating their successful implementation, can instill confidence and encourage their adoption.
- *Insufficient knowledge about energy efficiency and savings enabler technologies:* Progress might be limited by a lack of thorough understanding of energy efficiency and the enabling technologies.
- *Insufficient training of personnel:* To effectively implement energy efficiency measures, it is crucial to equip personnel with the necessary skills and knowledge. Establishing training programs that cater to diverse professional backgrounds and roles within the construction industry, including architects, engineers, contractors, and facility managers, can address this barrier.
- *Lack of sufficiently allocated financial resources:* Limited financial resources can impede the integration of energy efficiency initiatives. Educational efforts should emphasize the potential funding opportunities, such as government incentives, grants, and green financing, while also promoting cost-effective measures that provide immediate benefits and ensure a positive return on investment.

In the context of energy efficiency, legislation plays a crucial role in promoting effective cooperation and common interests among stakeholders. According to the International Energy Agency (IEA), a successful approach to implementing building energy regulations is to have a government coordination agency facilitating the development of training resources and compliance software, which are made publicly available to all stakeholders (Oettinger et al., 2013).

One notable initiative in the European Union that demonstrates the relevance of training in the construction industry is the BUILD UP Skills program. This initiative has been instrumental in providing training for craftsmen, on-site construction employees, and system installers across 28 EU Member States, highlighting the importance of coordinated efforts in enhancing energy efficiency practices (Commission, 2017). Blockchain technology offers a secure and transparent solution for training certification and labelling. By leveraging distributed ledger technology, Blockchain ensures the secure storage of records and enables information sharing within a community of users. Each member retains a unique copy of the information, and all members collaboratively verify any modification, ensuring trust and integrity of training and education content. Blockchain can be utilized to establish and maintain a reliable infrastructure for certifying and verifying energy efficiency training credentials (Risius & Spohrer, 2017).

The incorporation of Blockchain technology into the certification process enables the relevant authorities to securely authenticate learners' qualifications and provide credentials that are resistant to manipulation. The utilisation of cryptographic algorithms and the consensus mechanism within the Blockchain network can eliminate the need for third-party verification and control. The implementation of this approach not only improves the security and transparency of the certification process but also enables the sharing of certificates among learners during training programmes (Alexander et al., 2017).

This paper presents a comprehensive Blockchain-based training framework to support energy efficiency training labelling and authentication in the construction industry. We examine how energy efficiency training can be integrated with Blockchain, ensuring a heightened level of data dependability, integrity, and transparency throughout the process. Emphasizing the intersection of education and information technologies, our research underscores the pivotal role of educational solutions in promoting awareness and interventions to mitigate climate change. Central to our study is the innovative integration of Blockchain technology, a cutting-edge Information and Communication Technology (ICT) tool, to advance energy education within the construction sector, a significant contributor to global carbon emissions. Building on this, we demonstrate that Blockchain can play an instrumental role in the administration of construction projects, offering advanced functions for energy training that contribute to its broader implementation and acceptance. The proposed framework capitalizes on the functionalities of Blockchain, including smart contracts and mobile passports, to provide a secure and efficient approach for delivering training and education in the energy domain. By showcasing a case-study example and emphasizing the utilization of ICT resources, particularly Blockchain, we aim to meet the essential educational requirements in the construction industry regarding energy efficiency.

The remainder of the article is as follows: Section 2 provides various authoritative publications and case studies relevant to our line of research. Section 3 explains the methodology used to perform our study. This is followed by Section 4, which outlines a comprehensive set of analyses and applications of Blockchain for energy efficiency training. Section 5 outlines the analysis and significance of the findings. Section 6 presents the conclusion and future work.

2 Literature review

Energy efficiency training has been the subject of numerous projects and programmes that have been implemented across sectors. In the building sector, prominent initiatives such as the Energy Star programme in the United States and the certification programmes established by the Green Building Council have played a pivotal role in advancing the field of energy efficiency (Banerjee & Solomon, 2003). These programmes offer training and resources to individuals responsible for building management, including owners, facility managers, and occupants. The primary focus of these programmes is to promote energy-saving practises, optimise equipment usage for efficiency, and facilitate building retrofits. These programmes make a significant contribution towards the reduction of energy consumption and environmental impact in buildings by increasing awareness and promoting the adoption of best practices (Introna et al., 2014).

Furthermore, several industries have adopted energy efficiency training programmes as a mean to enhance the optimisation of energy consumption within their operational processes. Efforts such as the "Intelligent Energy Europe" initiative by the European Union prioritise the identification of energy-saving prospects, the implementation of energy management systems, and the provision of training to personnel on efficient operational practises. These programmes offer valuable resources and assistance to various industries, aiding them in the reduction of energy waste, enhancement of productivity, and attainment of substantial cost savings (Tanaka, 2011). In addition, there has been significant engagement from non-governmental organisations (NGOs) and non-profit entities in the provision of energy efficiency training. These organizations often collaborate with governments, businesses, and communities to provide training, resources, and guidance on energy-saving measures for the adoption of sustainable energy practices and technologies (Sovacool & Florini, 2012).

The current state of energy efficiency training faces several challenges and limitations. One prominent challenge is the fragmentation of data management systems. Energy efficiency programmes commonly depend on data obtained from various sources, including utility providers, building management systems, and consumer feedback. Data sources are often siloed and lack interoperability, making it difficult to integrate and analyze data effectively. Another significant challenge is the lack of trust and transparency in energy efficiency practices. Existing solutions often lacks transparency, making it challenging to validate reported energy savings and verify the integrity of data. This lack of trust can lead to scepticism and reluctance to participate in energy efficiency training initiatives, undermining their effectiveness (Armstrong & Banks, 2015). Moreover, the implementation of extensive training initiatives on a significant scale can impose a substantial demand on resources and create financial difficulties. The identification of cost-effective strategies for the delivery of training content, the engagement of diverse audiences, and the monitoring of progress play a pivotal role in facilitating the widespread acceptance and implementation of energy efficiency practices (Brychkov et al., 2023).

In order to effectively tackle these challenges, we argue that a Blockchain based educational system can bring substantial advantages related to decentralisation, immutability, and transparency in trainings and can address current limitations in energy efficiency training. The utilisation of Blockchain technology enables stakeholders to share and manage data related to energy efficiency training securely and transparently (Yap et al., 2023). Moreover, the utilisation of Blockchain has the potential to facilitate the effortless combination of diverse data sources, thereby establishing a comprehensive and reliable basis for energy efficiency training programmes (Schletz et al., 2020).

Blockchain provides greater trust in applications where collaboration is needed to ensure openness and accountability among the involved parties. The implementation of smart contracts enables process automation and monitoring of resources in real-time. Identity, authenticity, and legality can all be shown by the certificate, which serves as a single source of truth for transaction records and audit trails (Chang et al., 2019). Sun et al. (2018) present a Blockchain-based solution to the challenges of course consistency, credit and certification, student confidentiality, and online education, suggesting that Blockchain technology has significant potential for the future of education.

The Blockcerts project (Jirgensons & Kapenieks, 2018) was created in collaboration with the MIT Media Lab Learning Initiative and Learning Machine as an open-source ecosystem for developing, distributing, and verifying Blockchain-based education certifications. Basic information on training certificates includes the recipient's name, the name of the granting organisation, and the date of issuance. Education certificates are securely stored on a Bitcoin-based platform, are cryptographically signed and are unalterable, while the verification of transactions is achievable via the issuance of certificates and their content. Another Blockchain-based system, dubbed "CredenceLedger" enables stakeholders and appropriate third-party organisations to record readily verifiable proof of digital academic certification training in a Blockchain ledger (Arenas & Fernandez, 2018).

Lizcano et al. (2020) assess the potential advantages of Blockchain (or distributed ledger) technology and suggest a decentralised trust mechanism for transactions based on an academic coin. Applying this strategy enables Blockchain to be utilised to manage material, teaching, and certification procedures that are reviewed collectively by students, instructors, and employers, resolving inconsistencies between the academic and commercial sectors. Related initiatives examine in detail the primary benefits and risks associated with the use of Blockchain in the energy efficiency industry by introducing and analysing two case studies involving Blockchain implementations: (i) the UK Energy Company Liability Scheme and (ii) the Italian White Certification Program (Khatoon et al., 2019). Bcertificated-Study is such a Blockchain-based solution for certificate verification in open and remote learning programmes. The trainees' development is constantly monitored, since the educational certification process is based on the assessment of several actors (students, instructors, and authorities) (Ölmez et al., 2018).

Finema (2022) is a supplier of decentralised identity platforms that provides a new service called "Document Verification System" through Blockchain for the identification and verification of document management procedures. Open Certs (OpenCers, 2022), BitDegree (BitDegree, 2022), BCertificateD (Ölmez et al., 2018), Blockcerts (Blockcerts, 2022), Edgecoin (Edgecoinpay, 2022), BIMcert (BIMcert, 2022), Stampery (Stampery, 2022), Gradbase (Gradbase, 2022), Bulgarian Open Source University (University, 2022), CertiK (CertiK, 2022), Woolf University (Woolf, 2022), and Proof Of Existence (Poex.io, 2022) are further Blockchain-based certification and verification services (Barbero et al., 2021). Open Badges is a Blockchain platform that enables organisations to produce and distribute open badges for individuals to collect and share on the web. The acquired badges provide information about the bearer's abilities and the awarding organisation in the form of a portable picture file (Consortium, 2022). Smart contracts are sometimes referred to as "automatic and enforceable agreements", which enable significant differentiation and innovation via the usage of Blockchain technology. Similarly, Mikroyannidis et al. (2018) detail their experience developing and deploying smart Blockchain badges.

In this manuscript, we focus on Blockchain technology and its application for advancing energy efficiency education by removing barriers to distribution, certification, and verification of energy efficiency training. We argue that Blockchain can support the development of new tools and instruments, providing a scaled approach for delivering energy efficiency training for the Architecture, Engineering, and Construction (AEC) industry. In a world facing increasing environmental challenges and energy demands, the need for energy efficiency has become more critical than ever. Energy efficiency plays a crucial role in the worldwide effort to mitigate climate change and secure a sustainable future (Omer, 2008). The significance of education and training in equipping individuals with essential skills and knowledge remains undeniable, particularly in our efforts to optimize energy consumption and decrease greenhouse gas emissions (Hafez et al., 2023).

3 Methodology

The energy efficiency training solution proposed in this paper aims to equip individuals and organizations with the necessary knowledge and skills to optimize energy usage and promote sustainable practices. The solution involves a dynamic digital platform that facilitates the registration of training offers and learning outcomes from various training organizations. Accreditation organizations assess and publish accreditation outcomes, ensuring the quality and credibility of the training. Our research methodology, designed to ensure a comprehensive understanding of the topic, is structured in two main phases:

Phase 1: Exploring primary sources of evidence: This phase is grounded in firsthand insights. We initiated communication with experts within the construction industry, including our esteemed partner experts, in order to acquire comprehensive and detailed perspectives on energy efficiency practises. Our research direction was further improved through collaborative workshops with experts. Additionally, a case study analysis was conducted to provide a practical understanding of the real-world implications of utilising Blockchain in energy-efficiency training.

Phase 2: Exploring secondary sources of evidence: This phase involved a comprehensive literature review of academic papers, industry reports, and whitepapers, framing our primary research and providing a robust theoretical foundation. We also explored various digital solutions, focusing on their applicability in delivering energy education, aiming to identify best practices and innovative approaches.

The key contribution of the paper revolves around the integration of cutting-edge Blockchain technology into the energy efficiency training landscape. This technology ensures that training and skills development are securely and transparently recorded and shared, with individuals having ownership and control over their training records. The decentralized nature of Blockchain fosters a sense of self-sovereignty and trust in the system. As a result, our methodology, combining both primary and secondary sources of evidence, proposes new models and solutions to address training challenges, including tools for facilitating energy skills registers and digital solutions to support energy efficiency training and education.

- a. A Blockchain training network integrated into the training platform (www.energy-education.com) to support passports/registers for workers at the regional/-national level and support for their take up at the EU level.
- b. A mobile interface using QR codes integrated into the training platform for facilitating the comparison of workers' skills and qualifications between countries,
- c. A dedicated training service complemented with energy sustainability services to support and incentivise initiatives for home and building owners, and,
- d. A community of over 200 registered users from the field of energy efficiency aimed to facilitate new partnerships with producers and retailers.

Figure 1 illustrates the steps to ensure accurate training labelling demonstrating the functionality of the platform. A complete study has been conducted in the same manner, and the features provided by the Blockchain system for the Energy efficiency training platform were investigated to provide a thorough understanding of current state-of-the-art Blockchain applications. In light of the analyses and findings, a proposal for integrating Blockchain technology into the Energy efficiency training platform was developed. The Energy efficiency training platform has been integrated with Blockchain technology as part of this concept. The platform proposed Blockchain technology, and presented user interface (UI) were developed in response to previously provided and assessed needs: security, self-sovereignty, transparency, immutability, decentralisation, and collaboration. Semantic web and Blockchain technology have

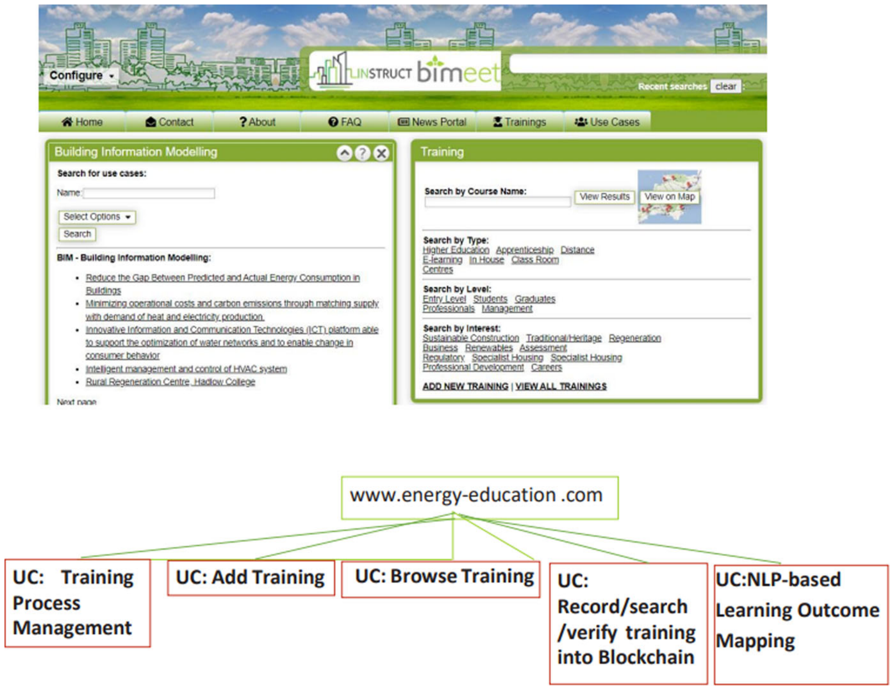

Fig. 1 The steps for ensuring training labelling

been presented as a solution to these requirements for developing the digital energy efficiency training platform.

4 A Blockchain supported energy-education platform

In general, integrating Blockchain into the training platform may contribute to increasing the platform's speed and efficiency. Trust, self-sovereignty, transparency, immutability, decentralisation, and collaboration are some of the primary benefits of using Blockchain technology in the training network. The fact that every user's action is tracked and recorded on the Blockchain eliminates the need for time-consuming file and document management. Since there would be no intermediary processes, the approval and verification phases of the process would be completed much faster. Enterprises, organisations, and individual users can independently validate and verify a certificate on a Blockchain network. However, there are limitations to using Blockchain technology. Globally, Blockchain technologies are under active development, and future developments may affect the training outcomes. A lack of research on labelling in the education sector makes the development of a general framework challenging when it comes to combining training with Blockchain. There are no systematic techniques or perspectives for evaluating the learning process and even fewer ways for equating traditional modes of instruction-books, courses, and online learning-with no approach capable of integrating these training aspects into a comprehensive training framework. It is challenging to consider scalability and storage factors to determine the expenses of sustaining energy efficiency training on a Blockchain platform.

Several colleges and organisations now use Blockchain technology to streamline the administration of academic degrees, and summative evaluation of learning outcomes (Skiba, 2017). Blockchain technology is capable of generating and formatting the transcript. This covers learning outcomes, student successes, and academic certificates in education and training. Further, the informal learning environment contains information on research, skills, online learning, and personal interests. These data may be stored and accessed securely through a Blockchain network.

4.1 Blockchain for digital energy education

Energy training labelling and authenticity may be achieved via the use of Blockchain technology. Blockchain has the capability of transforming the current Internet from a"Network of Information Sharing" into a "Network of Value Exchange" (Yousif, 2022), (Si et al., 2019). Businesses, industry, and education are all expected to be transformed by Blockchain technology and adhere to the development of knowledge-based economies throughout the world. As a result of the immutability, transparency, and trustworthiness of all transactions undertaken inside a Blockchain network, this cutting-edge technology has a wide variety of potential applications (Underwood, 2016)including a wide range of other industries as the applications have grown in scope and consistency over the years (Collins, 2016). A number of studies studied how Blockchain technology may be used in education (Devine, 2015), although researchers discussed the possible application of Blockchain technology (Swan, 2015). Several colleges and organisations are already using blockchain technology to streamline academic degree administration and summative evaluation of learning outcomes (Skiba, 2017), evidencing the capability to produce and formulate the transcript. The University of Nicosia has been the first institution to use Blockchain technology to retain MOOC certificates (Sharples & Domingue, 2016). Sony Worldwide Education developed a worldwide assessment platform that uses Blockchain technology to record and organise credential data (Hoy, 2017). In addition, MIT and Learning Machine worked on the development of a Blockchain-based digital certificate for online learning (Skiba, 2017). Blockchain technology has been able to construct data management structures in which users gain more ownership and control over their data might greatly decrease educational institutions' data management expenses and liability exposure due to data management difficulties (Belle, 2017).

4.2 Training platform workflow

The concept of autonomous and non-transferable digital identity is associated with training labelling, which does not involve a central administrator who could alter associated data or identities (Sun et al., 2018). Fridgen et al. (2018) published a manuscript on deploying two smart contracts to the Blockchain platform using an accrediting authority. While the first smart contract in this paper is designed to implement identification on the Blockchain platform, the second contract manages the life cycle of the certifications issued through the Blockchain. The participant's general information will be developed to determine the training, which will maintain a certain level of persistence over time. This smart contract will be stored on the Blockchain and will be utilised for the lifetime of its existence.

Each participant who accesses the energy efficiency training platform is provided with a Blockchain account. This account may be used to sign transactions and purchase for a variety of services, as well as to receive certifications and verify an individual's participation in these services as in Fig. 2. In the platform, there are two distinct types of Blockchain layouts with two smart contracts that can be used to interact with training assets. The first is a private smart contract, which needs trusted individuals to verify new users and create new blocks on the Blockchain as the primary profile for all network users. The other is a permissioned public deployment for managing new user registration and smart contract validation. Prior to training registration verification, users will be able to read data from the chain but not create new training transactions or extract/verify chain blocks. It is suitable for usage as a Smart contract for lifelong learning.

A new user's smart contract may be established at any moment and registered in the training network from any location. A second smart contract is created for the user who has already registered in the system, ensuring that they will be able to access the training through this account. This is a public account, which implies that any member of the public may see the network's transactions. By using a smart contract, all user activity on the training platform, such as training sessions and billing transactions, is recorded to the Blockchain. As a result, the system may track when and what training

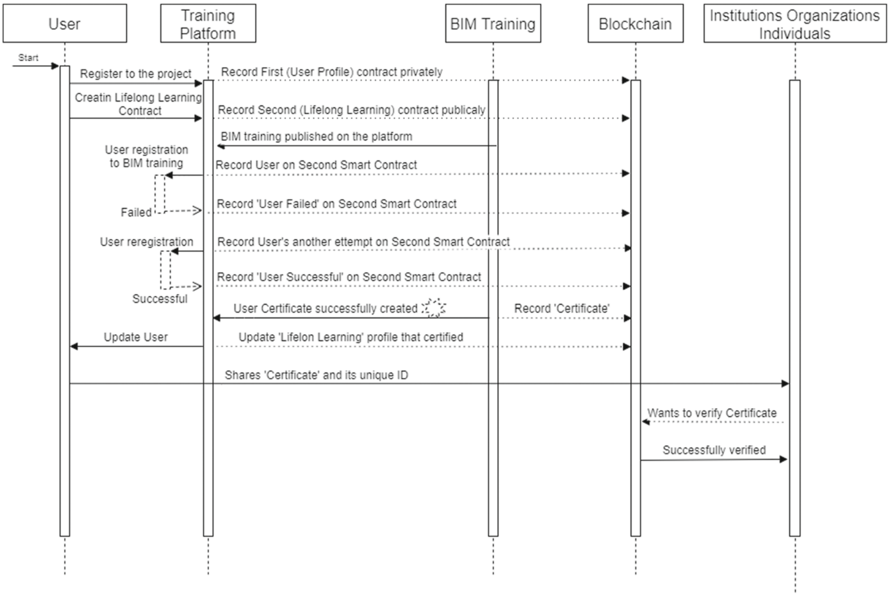

Fig. 2 The Blockchain-based training platform's workflow

has been completed, as well as the grade of the training, its validity, the expiration date, if applicable, and potential outcomes.

The following example illustrates how a smart contract may be used in education:

- When a user registers with the system, they generate a private contract known as a user profile.
- The individual utilises a Blockchain API to digitally sign the contract and generate a unique cryptographic hash on Blockchain.
- Using this unique hash, a public smart contract for lifetime learning is created.
- This newly constructed lifelong learning contract stores all training records of the user.
- The first contract in the user profile is used to validate the user's information. Lifelong learning is the second contract, and it is used to track and validate the user's learning.

4.3 Smart contract preparation

The integration of smart contracts into Blockchain technology has become a key development subject because it enables peer-to-peer transactions and public administration of databases in a transparent and trustworthy manner. Smart contracts are immutable and tamper-evident. Moreover, a smart contract encapsulates all transaction data and executes automatically. Additionally, the smart contract is deployed on multiple Blockchain platforms utilising the Solidity programming language.

We have used the *Remix Browser* platform to construct our *Solidity* codes. *Solidity* is a high-level programming language designed specifically for the purpose of developing smart contracts. Ethereum is a decentralised, open-source Blockchain platform with smart contract capability that is still under development.

The first smart contract is constructed in the form of a User Profile, which includes elements such as the user's forename, surname, date of birth, occupation, email, and country. The smart contract will expose the username and address to all users. However, the date of birth, email address, and other personally identifiable data will be stored as private information to protect individual privacy. Nevertheless, making the username and address public facilitates retrieval as part of an index.

Lifelong Learning is a separate contract that is publicly available and will be broadcast to the Blockchain network through personal training data. On the Blockchain network, users will be able to see the title and score of a training session, as well as the program's validity, link, and results. As a consequence, any organisation or institution will have access to all pertinent information about the training that has been undertaken and completed, the examination results and scores, and Internet URL of the training programme.

Step 1: First smart contract for the identification of individuals

Two smart contracts will be used to initialise the training platform. The first contract will be for credential management consisting of Forename, Surname, Birthday, Profession, Email and Country, as observed in Code Listing 1.

Listing 1 First smart contract for user profile

```
struct UserInfo {
    string Forename;
    string Surname;
    string Birthday;
    string Profession;
    string Email;
    string Country;
}
```

For privacy protection purposes, only the Forename and Surname fields will be publicly available, the rest only being shared privately within the network.

Step 2: A second smart contract is being developed to support lifelong learning

The second smart contract will be developed and utilised to record data supplied by the training platform. It will be an open ledger that will record all of the user's achievements and data, throughout the whole life cycle. When this second contract is used, the process will continue for the lifetime of the contract's life and will give an unchangeable ledger by retaining the user's own record. When the training information by using this second contract (as shown in Code Listing 2), the labelling process will continue perpetually, providing an unalterable record by retaining the participant's own record.

Listing 2 Second smart contract for lifelong learning

```
struct TrainingInfo {
    string trainingTitle;
    string trainingScore;
    string trainingOutcomes;
    string trainingLink;
    string trainingValidity;
}
```

4.4 Blockchain-based learning platform

Ethereum smart contracts are utilised to monitor client-provider interactions and to associate a training record with viewing rights and data retrieval instructions that may be performed in other databases. The cryptographic hash of the record on the Blockchain has also been included to ensure that this cannot be manipulated. New records can be created for a single training facility, and administrators can create and share training records on behalf of training providers. In both circumstances, the receiver of new data is alerted automatically and given the option of verifying the proposed record before accepting or rejecting it. This method keeps individuals informed and engaged in the progress of their data.

The implementation of smart contracts via browser-based User Interfaces via the WEB3 protocol, as well as the interaction with smart contracts via the WEB3.js library, have been widely cited and experimented with, particularly in light of the widespread adoption of the Ethereum Blockchain and the ERC20 Blockchain standard. Decentralized shared applications, IoT data transfers (Park et al., 2018), smart home management (Qashlan et al., 2020), and identity management (Benedict et al., 2021) are just some of the significant real-world utilisation of WEB3 user interfaces.

It is the primary goal of the Blockchain User Interface to accomplish two functions: (i) Interacting with the primary smart contract functionality to implement operations such as Add, Retrieve, and Verify, (ii) Visualizing the data present on the Blockchain in an intuitive format, such as that provides a fair and accurate illustration of the transaction, this volume will grow over time on the Blockchain, there will be a development in the number and use of Blockchain transactions as it is seen in Fig. 3. In addition, there is a description of the training types produced, the outcomes of their delivery, and the institution providing them. In addition, it contains a record of historical transactions for categories, approval stamps, and their position as independent validators.

For the transaction ledgers, we utilise line charts, pie charts, bar charts, and data-rich tables for data visualisation and analytics. These components are organised into widgets. Interactive exploration and iterative view refinement are generally accepted principles in visual analytics. Users may adjust their queries and visualisation style by interacting with their data in various ways. We are investigating using natural language interaction with a mouse and touch-based input for visual analytics. Direct manipulation is effective when pointing to items of interest (e.g., lassoing a cluster of points). Figure 4 illustrates the logical sequence of the actions taken by the user across the various views of the Blockchain UI.

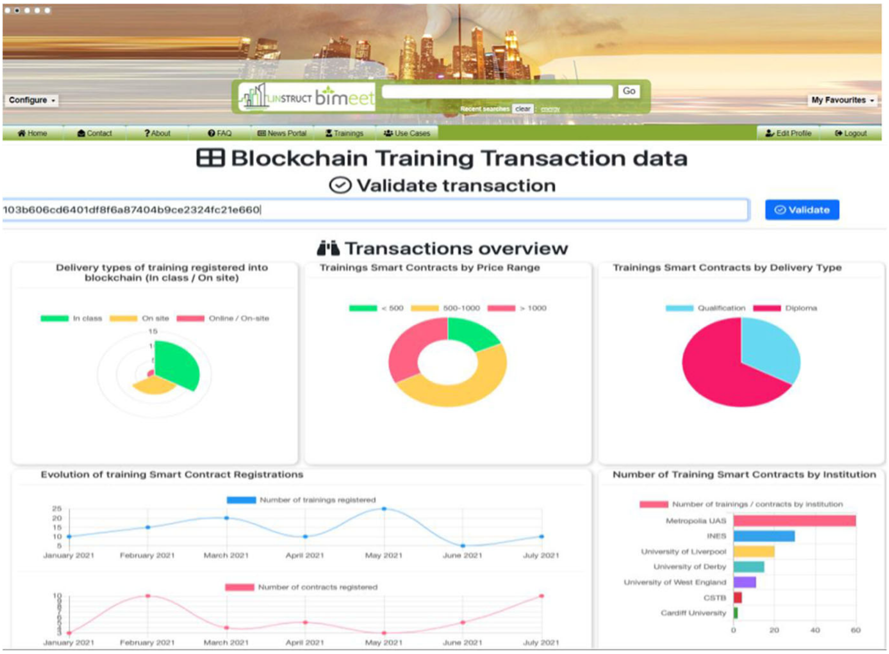

Fig. 3 The Blockchain Transaction Data Dashboard: History of smart contract deployment transactions by institution, price range, delivery type and outcome type

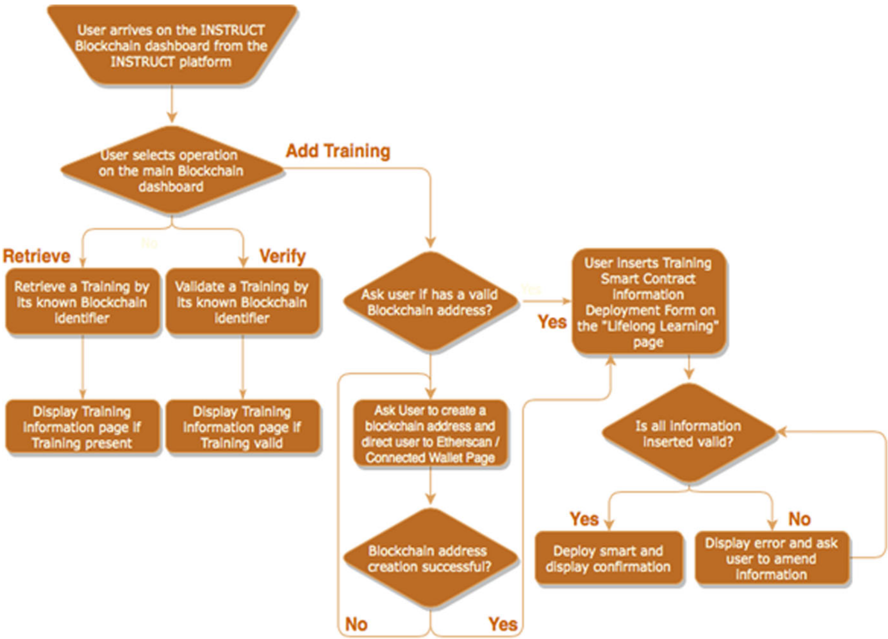

Fig. 4 User flow diagram for blockchain UI

Users are directed to their dashboard (the platform's landing page), which presents them with several possible actions to take. The transaction overview may be visualised, and various actions that can be performed, such as turning on and off the widget display and filtering the data in the charts. After inputting the transaction ID, users are prompted to choose between two alternatives (Retrieve / Verify) for retrieving or authenticating a training. If the training is legitimately accessible on the Blockchain, the transactions associated with it will be revealed (as well as their metadata). To give their transaction identification (ID), block (block time), timestamp (TIM), and action (ACTION), the user must authenticate using an Ethereum/ERC20 wallet or Etherscan/the wallet website. After confirming a user's identification, the option to build a smart contract for a new training programme becomes accessible.

Figure 5 illustrates an example of a successful transaction.

Additionally, participants may utilise QR codes generated by the Blockchain UI on their mobile devices to verify that their data has been successfully recorded into the Blockchain. Training requirements may be recorded into the Blockchain network, making it easier for users to track their qualifications while enabling training authenticity and identification to be tracked through a mobile app with QR capabilities.

The Blockchain UI is compatible with devices and gives QR codes to verify whether a user has been logged in to the Blockchain, as seen in Fig. 6. As a result, users will be able to log their training requirements into the Blockchain network, and they will also be able to utilise the mobile app to authenticate their training.

4.5 Authentication and verification

User Interface has a two-tiered authentication mechanism with an interface accessible exclusively to those with a valid account and confirmed email address on the platform.

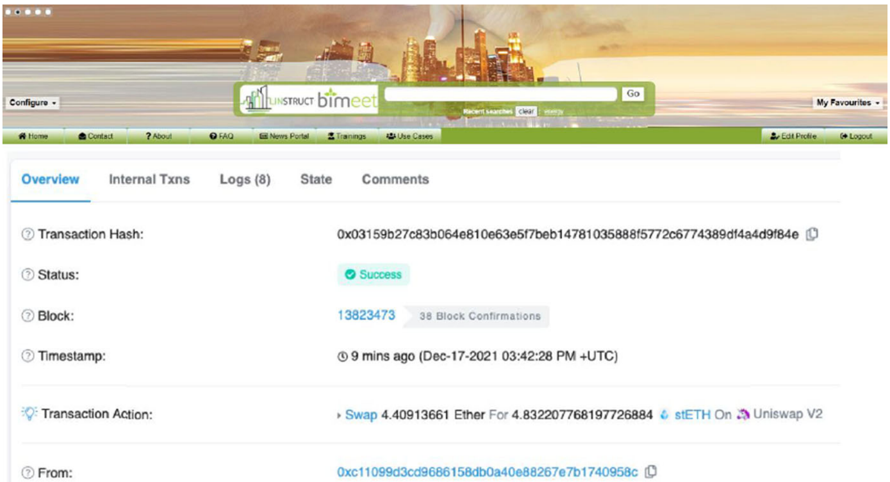

Fig. 5 An example of a successful transaction

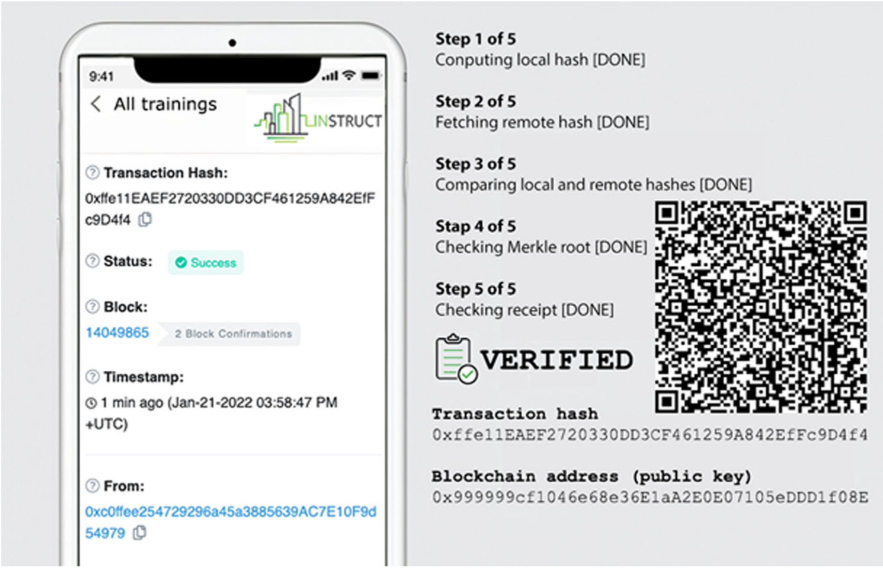

Fig. 6 Blockchain-based mobile application

Users must identify themselves using a legitimate Ethereum wallet that supports the WEB3 authentication protocol.

Training may be confirmed at any time in the Blockchain system via the use of a unique hash code that is divided into two phases:

Phase 1: Certification of authorised users

Authorised users manage user records, learning programs, and other associated rules, as well as test results stored in databases or Microsoft Excel sheets. This information is utilised to create printed certificates for learners. As a result, authorised users' primary function is to import data and test results from legacy systems. After importing the data, authorised users may view the produced certificates. Additionally, certifying authorities have the option of scanning for learners or obtaining an overview of learners and their credentials as a result of learning courses. The summary invites authorised users to create a single record for all training certificates.

Another critical feature for authorised users of certification is the authenticity of certificates and their protection in the Blockchain. The process follows Participant / Data (Hash) / Signed Record / Network Sharing / Verifier / Hash Checking, respectively. If it matches the previously stored hash, the user is granted access to the system.

Phase 2: Learner-friendly features

Students or trainees often gather paper certificates that have built-in security mechanisms. Trainers often provide digitised (scanned) or authorised copies of their documents to prospective employers through email. Thus, importing certifications and developing an application portfolio is an essential requirement of a successful product. Additionally, learners require tools for managing and disseminating their application portfolios (Fridgen et al., 2018). Blockchain technology enables students to create a secure artefact that can be utilised globally and shared with other parties (i.e. an employer). These third parties' operations, such as reading or validating certificates, are supported digitally and are easily verifiable.

4.5.1 Label for lifelong learning and knowledge control

In order to support lifelong learning and knowledge control, the following process can be implemented:

Completion and Verification: After participants successfully complete a training program and examination, their results are evaluated against the predefined conditions within a smart contract. For instance, if the grade is greater than 70 percent, the smart contract registers the transaction on the Blockchain, ensuring a secure and immutable record.

Periodic Evaluation: As time elapses, the smart contract automatically triggers self-execution at regular intervals. During this process, it conducts a quiz to assess the ongoing validity of the provided label. By testing participants' knowledge and skills related to energy efficiency training, the quiz serves as a means of continuous evaluation and reinforces the importance of retaining and applying acquired information.

Reminder and Update: The periodic quiz not only verifies the validity of the label but also serves as a reminder of previous energy efficiency training and information. Participants are prompted to recall and reinforce their knowledge, encouraging them to stay engaged and up to date with relevant practices.

Autonomous Operation: The smart contract operates without the need for a third party. It independently updates and disseminates the specified label on the network, ensuring transparency and reliability. This decentralized approach fosters trust among participants and eliminates the reliance on intermediaries.

Survey and New Certification: The platform can leverage the smart contract to send participants follow-up surveys. Recognizing the participants' existing certificate, the system prompts them to complete the survey. Based on their responses, a new certificate can be generated, reflecting their continuous learning and development.

By incorporating these steps, the system establishes a comprehensive framework for lifelong learning and knowledge control. It encourages participants to maintain and update their skills while ensuring the accuracy and relevance of their certifications. This approach empowers individuals to contribute to their professional growth and adapt to evolving industry standards and practices.

4.5.2 Smart contract deployment

The smart contract is deployed on the Ethereum Remix platform with the transaction completed and training information recorded to Blockchain. The gas value rate, for instance, is determined by the transaction's author who must pay ($gasprice * gasamount$) from the sending account. Variable costs in Ethereum impact all organisations since the cost of executing smart contract changes with the application properties. Ethereum has the potential to increase scalability and decrease the amount of computational power required to validate transactions. Consequently, these transactions are expected to be quite affordable from a cost perspective. The "UserProfile" contract deployment result is shown in Listing 3.

Listing 3 Successful deployment of the user profile contract

```
[vm] from: 0x5B3...eddC4 to: UserProfile.(constructor) value: 0 wei data: 0x608...20029 logs:
0 hash: 0xe82...75acb
    status true Transaction mined and execution succeed
    transaction hash: 0xe82aeb288a240841220272e05d7a9fa34d30f0717f0524332b361ae1f9075acb
    from: 0x5B38Da6a701c568545dCfcB03FcB875f56beddC4
    to: UserProfile.(constructor)
    gas: 80000000 gas
    transaction cost: 1720129 gas
    execution cost: 1720129 gas
    hash: 0xe82aeb288a240841220272e05d7a9fa34d30f0717f0524332b361ae1f9075acb
    input: 0x608...20029
    val: 0 wei
```

Variable costs in Ethereum impact all organisations since the cost of executing a smart contract changes significantly. The user uses a Blockchain API to digitally sign the contract and generate a unique cryptographic hash for the contract's recording to the Blockchain. Using this unique password, the user then constructs a public "Lifelong Learning" smart contract. This newly constructed "Lifelong learning" contract stores all of the user's training records. While the first "User Profile" contract is used to validate the user's personal information, the second contract, titled "Lifelong Learning", is used to track and validate the user's educational instruction. This enables institutions, companies, and other government entities to monitor all of the certifications and training data of users.

4.6 Analytics and insights for energy efficiency education

The Blockchain technology serves as a robust advocate for data protection and security, and its inherent distributed and decentralized infrastructure facilitates seamless and secure knowledge sharing among individuals. As an alternative to conventional platforms, the proposed energy efficiency training platform has been thoughtfully designed to align with the specific requirements and demands of the education sector.

By leveraging the power of Blockchain, the energy efficiency training platform ensures the integrity and immutability of training records and skills registers. The decentralized nature of the platform empowers individuals to have full ownership and control over their training data, instilling a sense of self-sovereignty and trust in the system. This feature becomes especially critical in the context of sensitive information such as personal credentials and qualifications, where data protection is of utmost importance. Moreover, the distributed architecture of the platform promotes a collaborative environment, enabling seamless and efficient sharing of knowledge and best practices among energy efficiency professionals, training organizations, and other stakeholders. This encourages the exchange of innovative ideas and novel approaches, ultimately enhancing the overall effectiveness and impact of energy efficiency training.

The energy efficiency training platform prioritises a user-centric approach, aiming to provide a user-friendly experience for individuals of various skill levels. This includes learners who are seeking to acquire new skills as well as organisations that offer training programmes. The platform's user-friendly interface enhances navigability and accessibility, providing it an inclusive and empowering resource for a diverse range of users. Furthermore, the scalability and adaptability of the platform make it highly suitable for supporting the dynamic nature of energy efficiency training and education. As the field progresses and new technologies and practices emerge, the platform can seamlessly integrate the latest web and semantics technological advancements, ensuring that learners stay up-to-date with the most relevant and cutting-edge information.

The users of a blockchain-based platform and their interaction data are stored in a distributed ledger. Blockchain technology enables the construction of a permanent, public data ledger and provides global data transparency. The information cannot be modified without the consent of 51 percent of all users. It also assists in resolving the issue of missing data and ensuring the data's validity and security.

The experts have been asked to explain the role of Blockchain in energy efficiency training and education and how it can transform industry practices. The answers presented in Fig. 7 show the percentage of responses around how various services can be facilitated by Blockchain for the delivery of energy efficiency training and education. Notably, "Energy skills recognition within a consortium of partners" received significant attention, with 46.5% of experts highlighting its potential. This underscores the belief that Blockchain can revolutionize skills validation and collaboration within the industry. Furthermore, a substantial 74.4% of experts advocated for "Sustainable energy skills passports/registers for workers at regional/national levels", emphasizing the need for a decentralized system to verify and track qualifications, promoting transparency and trust. Additionally, 37.2% of respondents emphasized the value of "Mobile applications facilitating the comparison of workers' skills and qualifications" through Blockchain, making it easier for individuals and employers to assess skills efficiently. Blockchain's capacity to catalyze "New partnerships and contracts between producers and retailers" resonated with 41.9% of experts, illustrating how it can streamline industry collaborations and transactions. Lastly, 25.6% of respondents pointed to Blockchain's ability to "Incentivize legislative initiatives or public procurement practices", showcasing its potential to drive policy changes and promote sustainable practices. As a result, it is widely agreed among experts that Blockchain technology possesses significant potential for transformation within the field of energy efficiency

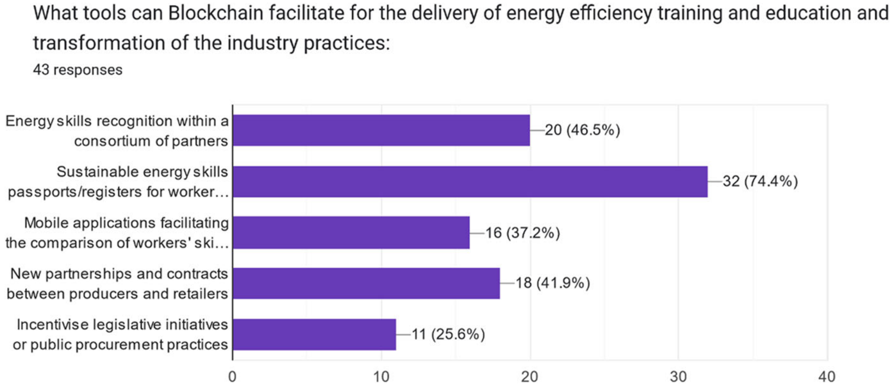

Fig. 7 Experts perspective for the role of Blockchain in energy efficiency training and education

Fig. 8 Platform analytics for geolocation

training and education. This potential is based on its ability to improve efficiency, transparency, and trust the industry and associated supply chains.

Figure 8 presents the platform analytics using geolocation and demonstrates the potential of Blockchain technology in promoting the freedom of information and its decentralized nature. This decentralized platform simplifies the process for users to share their knowledge, allowing for seamless and secure data exchange across the network. The application of Blockchain in various domains, including energy efficiency training, demonstrates its capacity to address challenges of inconsistent data by establishing a permanent and transparent record accessible to the public. By anchoring data in an immutable and distributed ledger, Blockchain reinforces data integrity and eliminates the risk of tampering or manipulation, ensuring the credibility of shared information.

The databases powered by Blockchain technology organise data in a more structured manner than traditional databases. Furthermore, blockchain enables increased efficiency in utilising and analysing relevant data and information. Blockchain technology provides an effective solution to apply the validation of data and the issue of managing fraudulent information.

5 Discussion

Through our analysis, we have demonstrated that Blockchain can play a pivotal role in developing new tools and instruments in the education sector, providing a scalable approach to delivering energy efficiency training for the AEC industry. Based on empirical evidence from our primary research sources, one of the key advantages of using Blockchain in energy efficiency education is its ability to remove intermediaries and central authorities, promoting a peer-to-peer network that promotes trust and efficiency in data exchange. Training providers can directly register their courses and learning outcomes on the Blockchain, ensuring transparency and integrity in the certification process. Accreditation organizations can then assess and publish accreditation outcomes, providing employers and learners with verified and reliable training credentials. Moreover, the immutability of data on the Blockchain ensures that training records and certifications remain tamper-proof and secure. This empirical observation addresses the problem of inconsistent data in traditional systems, instilling confidence in the accuracy and validity of training achievements.

The potential for Blockchain to create a global and decentralized network for energy efficiency training is particularly significant with the emerging concerns around digital divides and reticence around the adoption of technology in education. From our interactions with industry experts, by removing geographical barriers and enabling international recognition of certifications, Blockchain can increase collaboration and knowledge exchange among energy efficiency professionals worldwide. This interconnected network can lead to the emergence of best practices, innovative solutions, and continuous improvement in the field.

However, despite the promising opportunities, there are also challenges to consider when implementing Blockchain in energy efficiency education. Based on feedback from our partner experts, the adoption of this technology requires careful consideration of key factors such as scalability, data privacy, and interoperability with existing systems. Ensuring that the Blockchain infrastructure can handle a growing number of training records and transactions while maintaining data privacy and security will be critical to its success. Moreover, collaboration and cooperation among industry stakeholders, regulatory bodies, and technology providers will be essential to create standardized protocols and frameworks for Blockchain-based energy efficiency training. It is our opinion that a collective effort is necessary to ensure that the platform's architecture aligns with industry needs, maintains user-friendliness, and maximizes the potential for knowledge sharing and collaboration.

In the rapidly evolving landscape of education, our research introduces several novel contributions that address both the specific needs of energy efficiency training in the construction industry and broader educational challenges. Firstly, we present a transformative approach to fostering trust in educational certifications through Blockchain's decentralized nature. This system allows for the verification of educational credentials without the reliance on central authorities, streamlining the process and minimizing potential biases. Furthermore, our framework emphasizes the potential of Blockchain to transcend geographical barriers, facilitating international recognition of certifications. This promotes a global collaborative educational environment, especially vital in specialized fields like energy efficiency where expertise is globally dispersed. Another significant advancement is the integration of smart contracts, automating various educational processes from registration to certification. This automation not only ensures efficiency but also significantly reduces administrative burdens traditionally associated with these tasks. Addressing the challenge of data integrity in education, our study underscores Blockchain's capability to ensure that educational records remain tamper-proof, addressing a long-standing issue of record authenticity. Lastly, our research bridges the gap between academic offerings and industry demands in energy efficiency training. By fostering collaborative evaluations involving diverse stakeholders, we ensure that educational content remains relevant and aligned with real-world requirements. While our primary focus is on energy efficiency training for the construction sector, the implications and innovations presented have broader relevance, marking significant advancements in the general educational domain.

5.1 Implications for the educational context

The implementation of Blockchain technology within the context of energy training provides significant impact in the construction sector and provides valuable solution for the entire education domain. Using primary research sources, we have evidenced that Blockchain technology provides a foundation for enhanced data dependability, integrity, and transparency in energy efficiency training. The immutability and cryptographic security features of Blockchain ensure that training records are trustworthy and tamper-proof. This increased transparency fosters trust among stakeholders, such as students, instructors, and employers, by offering a verifiable and reliable source of training data. Furthermore, the collaborative nature of Blockchain enhances collaboration and accountability in energy efficiency training. Based on our case studies, through the implementation of smart contracts, training processes can be automated and monitored in real-time. This automation reduces administrative burdens, streamlines resource allocation, and enables more effective collaboration among stakeholders with a more efficient and streamlined educational ecosystem for energy efficiency training.

Within the context of energy education, the utilisation of Blockchain technology serves to address inconsistencies that exist between the academic and commercial fields in relation to energy efficiency training. As noted by Lizcano et al. (2020), the implementation of decentralised trust mechanisms offers a potential solution to address the discrepancies that exist between material, teaching methods, and certification procedures. This facilitates the implementation of collaborative evaluations involving students, instructors, and employers, thereby ensuring that educational offerings are in alignment with industry demands and promoting a seamless transition for learners.

The proposed training framework presents a scalable solution for providing energy efficiency training in the AEC industry using distribution mechanisms, certification procedures, and verification protocols to enable the development of standardized and efficient energy efficiency training programs. Using our secondary research sources, we have developed a framework that provides a structured educational model for future researchers and practitioners to develop wider education and training programs in the construction sector.

5.2 Training labelling and learning outcomes

Learning outcomes are usually examples of what a learner should know, understand, and be able to accomplish after completing a learning activity. From our literature review, a basic framework of learning outcomes and certain action verbs are required to establish taxonomy levels in cognitive research. A learning outcomes methodology gathers, develops, and verifies the required experience, abilities, and competencies including energy efficiency skills, expertise, competence, and learning outcomes for various stakeholders (Suwal et al., 2019).

Energy efficiency training labels give the required data to confirm individuals' certifications to assure the legitimacy of training in different countries. As observed from our primary research sources, academic references and courses taken are valued as indications of mastering particular competencies and skills by educational institutions, including governments. As a result of Blockchain labelling, such training may be considerably increased in value and contribute to lifetime learning (Alammary et al., 2019). Such digital solution can enable permanent, reliable, and safe administration of many participants and promotes lifelong learning by providing users with direct access to and control over their accomplishments. Additionally, such technology encourages a positive attitude toward learning by respecting user-centered and multifaceted educational approaches.

6 Conclusion

Blockchain technology provides a secure distributed ledger that enables decentralised, trustworthy, secure, and transparent systems with application for the education domain. This paper contributes to the current body of knowledge by introducing a Blockchain technology to the educational environment proposing a Blockchain-based training platform to address energy efficiency in the construction sector. In addition, a mobile interface is provided utilising QR codes integrated into the platform to simplify the worldwide comparison of employee abilities and certifications. The work evidences how digital technologies can be built for an energy efficiency training platform, demonstrating the platform's development through the concept of a Blockchain-based training platform and providing an integrated user interface.

The findings indicate that Blockchain applications in education administration are still in their infancy. However, they are rapidly gaining importance in several fields of education, such as certification and creating collaborative platforms for lifelong learning. The utilisation of the Blockchain technology offers a potential opportunity to enhance the security of user data in a digital environment. On a network built on Blockchain, each user has the same rights and options based on an open, unregulated, and permissionless system that guarantees that everyone has equal access to educational resources and to the underlying technology and network. In such an environment, instructors, students, and users can use Blockchain to avoid loss of data and ensure persistence in verification in case the organisation that issued it no longer exists. Furthermore, a variety of stakeholders, such as potential employers and institutions, as well as prospective employees, organisations, and students can benefit from the use of a Blockchain based energy training platform.

Acknowledgements The authors would like to acknowledge the financial support from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 894756.

Data Availibility All data generated or analysed during this study are included in this published article (and its supplementary information files).

References

Alammary, A., Alhazmi, S., Almasri, M., & Gillani, S. (2019). Blockchain-based applications in education: A systematic review. *Applied Sciences, 9*(12), 2400. https://doi.org/10.3390/app9122400

Alexander, G., Camilleri, A. F., & Inamorato Dos Santos, A. (2017). Blockchain in Education. Number KJ-NA-28778-EN-N. Luxembourg (Luxembourg): Publications Office of the European Union. https://doi.org/10.2760/60649.

Alhamami, A., Petri, I., Rezgui, Y., & Kubicki, S. (2020). Promoting energy efficiency in the built environment through adapted bim training and education. *Energies, 13*(9), 2308. https://doi.org/10.3390/en13092308

Almadani, M. S., Alotaibi, S., Alsobhi, H., Hussain, O. K., & Hussain, F. K. (2023). Blockchain-based multi-factor authentication: A systematic literature review. *Internet of Things, 23*, 100844. https://doi.org/10.1016/j.iot.2023.100844

Alshahrani, M., Beloff, N., & White, M. (2021). Towards a blockchain-based smart certification system for higher education: an empirical study. *International Journal Of Computing and Digital System*. https://doi.org/10.12785/ijcds/110145

Arenas, R., & Fernandez, P. (2018). Credenceledger: A permissioned blockchain for verifiable academic credentials. In *Conference: 2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC) At: Stuttgart, Germany* (pp. 1–6). https://doi.org/10.1109/ICE.2018.8436324

Armstrong, V. N., & Banks, C. (2015). Integrated approach to vessel energy efficiency. *Ocean Engineering, 110*, 39–48. https://doi.org/10.1016/j.oceaneng.2015.10.024. energy Efficient Ship Design and Operations.

Backlund, S., Thollander, P., Palm, J., & Ottosson, M. (2012). Extending the energy efficiency gap. *Energy Policy, 51*, 392–396. https://doi.org/10.1016/j.enpol.2012.08.042

Banerjee, A., & Solomon, B. D. (2003). Eco-labeling for energy efficiency and sustainability: a meta-evaluation of us programs. *Energy Policy, 31*(2), 109–123. https://doi.org/10.1016/S0301-4215(02)00012-5

Barbero, I., Petri, I., Celik, Y., & Rezgui, Y. (2021). Requirements for new instruments for skills recognition in the construction industry. https://instructproject.eu/wp-content/uploads/2021/10/INSTRUCT_Requirements-for-new-instruments.pdf

Barbero, I., Petri, I., Lapit, K., & Rezgui, Y. (2022). Evidencing the correlation between training and energy efficiency. https://instructproject.eu/wp-content/uploads/2021/10/INSTRUCT-Correlation-between-training-and-energy-efficiency.pdf

Barker, T., Bashmakov, I., Bernstein, L., Bogner, J., Bosch, P., Dave, R., Metz, B., & Nabuurs, G. (2009). *Contribution of Working Group III to the Fourth Assessment Report of the IPCC : Technical Summary* (pp. 27–93). Cambridge University Press.

Belle, I. (2017). The architecture, engineering and construction industry and blockchain technology. *Digital Culture, 2017*, 279–284.

Benedict, J.N., Udhayakumar, S., Vikram, B.R., & Vignesh, C. (2021). Identity management using blockchain network for fail-safe e-governance. In P. Suresh, U. Saravanakumar, & M.S. Hussein Al Salameh (Eds.), *Advances in Intelligent Systems and Computing book series* (AISC, volume 1163) (pp. 747–757). Springer Singapore.

BIMcert. (2022). Bimcert certification, training and consultancy. http://www.bimcert.org/. Accessed 20 Nov 2022.

BitDegree. (2022). Learn & earn: Track cryptocurrency prices & learn crypto! https://www.bitdegree.org/. Accessed 20 Nov 2022.

Blockcerts. (2022). Blockchain credentials. https://www.blockcerts.org/. Accessed 20 Nov 2022.

Brychkov, D., Goggins, G., Doherty, E., Romero, N., Roudil, N., Di Trani, A., Singh, A., Smit, S., McLoughlin, E., de Castro Rodrigues Lima, R., et al. (2023). A systemic framework of energy efficiency in schools: experiences from six european countries. *Energy Efficiency, 16*(4), 21.

CertiK. (2022). Certik blockchain security leaderboard. https://www.certik.com/. Accessed 20 Nov 2022.

Chang, S. E., Chen, Y. C., & Lu, M. F. (2019). Supply chain re-engineering using blockchain technology: A case of smart contract based tracking process. *Technological Forecasting and Social Change, 144*, 1–11. https://doi.org/10.1016/j.techfore.2019.03.015

Chiş, D., & Caramihai, M. (2023). Blockchain in higher education: A secure traceability architecture for degree verification. In D.S. Mistretta, (Ed.), *Reimagining Education - The Role of E-learning, Creativity, and Technology in the Post-pandemic Era*. Rijeka: IntechOpen. https://doi.org/10.5772/intechopen.1001997.

Collins, R. (2016). Blockchain: A new architecture for digital content. *EContent, 39*(8), 22–23.

Commission, E. (2017). About build up skills. https://build-up.ec.europa.eu/en/bup-skills

Consortium, I.G. (2022). Ims open badges. https://content.1edtech.org/badge-count-2022/

Das, D., Banerjee, S., Chatterjee, P., Ghosh, U., & Biswas, U. (2023). Blockchain for intelligent transportation systems: Applications, challenges, and opportunities. *IEEE Internet of Things Journal,* 1–1. https://doi.org/10.1109/JIOT.2023.3277923

Devine, P. (2015). Blockchain learning: can crypto-currency methods be appropriated to enhance online learning? In *ALT Online Winter Conference 2015, 7-10 Dec 2015*.

Edgecoinpay. (2022). World's first educational digital token stable coin. https://edgecoinpay.com/. Accessed 20 Nov 2022.

Ferri, F., Grifoni, P., & Guzzo, T. (2020). Online learning and emergency remote teaching: Opportunities and challenges in emergency situations. *Societies*, *10*(4). https://doi.org/10.3390/soc10040086

Finema. (2022). Decentralized identity platform. https://finema.co/decentralized-identity-101/

Fridgen, G., Guggenmoos, F., Lockl, J., Rieger, A., & Schweizer, A. (2018). Developing an evaluation framework for blockchain in the public sector: the example of the german asylum process. In *Proceedings of 1st ERCIM Blockchain Workshop 2018. European Society for Socially Embedded Technologies (EUSSET)*. https://doi.org/10.18420/blockchain2018

Gilmore, R.O., Adolph, K.E., Millman, D.S., Gordon, A. (2016). Transforming education research through open video data sharing. *Advances in Engineering Education, 5*(2), http://advances.asee.org/wp-content/uploads/vol05/issue02/Papers/AEE-18-Gilmore.pdf.

Gradbase. (2022). Reinventing hiring. the right way. https://www.gradba.se/en/. Accessed 20 Nov 2022.

Hafez, F. S., Sa'di, B., Safa-Gamal, M., Taufiq-Yap, Y., Alrifaey, M., Seyedmahmoudian, M., Stojcevski, A., Horan, B., & Mekhilef, S. (2023). Energy efficiency in sustainable buildings: A systematic review with taxonomy, challenges, motivations, methodological aspects, recommendations, and pathways for future research. *Energy Strategy Reviews, 45*, 101013. https://doi.org/10.1016/j.esr.2022.101013

Hoy, M. B. (2017). An introduction to the blockchain and its implications for libraries and medicine. *Medical Reference Services Quarterly, 36*, 273–279. https://doi.org/10.1080/02763869.2017.1332261

Introna, V., Cesarotti, V., Benedetti, M., Biagiotti, S., & Rotunno, R. (2014). Energy management maturity model: an organizational tool to foster the continuous reduction of energy consumption in companies. *Journal of Cleaner Production, 83*, 108–117. https://doi.org/10.1016/j.jclepro.2014.07.001

Jirgensons, M., & Kapenieks, J. (2018). Blockchain and the future of digital learning credential assessment and management. *Journal of Teacher Education for Sustainability, 20*(1), 145–156. https://doi.org/10.2478/jtes-2018-0009

Khatoon, A., Verma, P., Southernwood, J., Massey, B., & Corcoran, P. (2019). Blockchain in energy efficiency: Potential applications and benefits. *Energies, 12*(17), 3317.

Kumar, M., Raj, H., Chaurasia, N., & Gill, S. S. (2023). Blockchain inspired secure and reliable data exchange architecture for cyber-physical healthcare system 4.0. *Internet of Things and Cyber-Physical Systems, 3*, 309–322. https://doi.org/10.1016/j.iotcps.2023.05.006

Lizcano, D., Lara, J., White, B., & Aljawarneh, S. (2020). Blockchain-based approach to create a model of trust in open and ubiquitous higher education. *Journal of Computing in Higher Education, 32*. https://doi.org/10.1007/s12528-019-09209-y

Mikroyannidis, A., Domingue, J., Bachler, M., & Quick, K. (2018). Smart blockchain badges for data science education. In *2018 IEEE Frontiers in Education Conference (FIE)*. https://doi.org/10.1109/FIE.2018.8659012

Oettinger, G., Rosenfeld, A., & Tricoire, J. P. (2013). Visualising the "hidden" fuel of energy efficiency. *Journal of International Energy Agency Spring, 4*, 1–48.

Ölmez, A.C., Öksüzer, Ş., Adnan, M., & Karaarslan, E. (2018). A blockchain-based certification system for education: Bcertificated. In *Future-Learning 2018, September 11-14*. İstanbul: Istanbul University Press.

Omer, A. M. (2008). Energy, environment and sustainable development. *Renewable and Sustainable Energy Reviews, 12*(9), 2265–2300. https://doi.org/10.1016/j.rser.2007.05.001

OpenCers. (2022). An easy way to check and verify your opencerts certificates. https://www.opencerts.io/. Accessed 20 Nov 2022.

Park, J. S., Youn, T. Y., Kim, H. B., Rhee, K. H., & Shin, S. U. (2018). Smart contract-based review system for an iot data marketplace. *Sensors, 18*, 3577. https://doi.org/10.3390/s18103577

Poex.io. (2022). Poex.io proven open excellence. https://www.proofofexistence.com/. Accessed 20 Nov 2022.

Qashlan, A., Nanda, P., He, X. (2020). *Automated Ethereum Smart Contract for Block Chain Based Smart Home Security* (pp. 313–326). Springer. https://doi.org/10.1007/978-981-13-8406-6_31.

Rezgui, Y., Miles, J.. Harvesting and managing knowledge in construction: from theoretical foundations to business applications. Routledge, 2011. https://doi.org/10.4324/9780203876091.

Risius, M., & Spohrer, K. (2017). A blockchain research framework: What we (don't) know, where we go from here, and how we will get there. *Business & Information Systems Engineering, 59*, 385–409. https://doi.org/10.1007/s12599-017-0506-0

Rustemi, A., Dalipi, F., Atanasovski, V., & Risteski, A. (2023). A systematic literature review on blockchain-based systems for academic certificate verification. *IEEE Access,* https://doi.org/10.1109/ACCESS.2023.3289598

Schletz, M., Cardoso, A., Prata Dias, G., & Salomo, S. (2020). How can blockchain technology accelerate energy efficiency interventions? a use case comparison. *Energies, 13*(22), 5869.

Schroeder, A., Minocha, S., & Schneider, C. (2010). The strengths, weaknesses, opportunities and threats of using social software in higher and further education teaching and learning. *Journal of computer assisted learning, 26*(3), 159–174. https://doi.org/10.1111/j.1365-2729.2010.00347.x

Sharples, M., & Domingue, J. (2016). The blockchain and kudos: A distributed system for educational record, reputation and reward. In *European conference on technology enhanced learning* (pp. 490–496). Springer. https://doi.org/10.1007/978-3-319-45153-4_48

Si, H., Sun, C., Li, Y., Qiao, H., & Shi, L. (2019). Iot information sharing security mechanism based on blockchain technology. *Future Generation Computer Systems, 101*, 1028–1040. https://doi.org/10.1016/j.future.2019.07.036

Skiba, D. (2017). The potential of blockchain in education and health care. *Nursing education perspectives, 38*, 220–221. https://doi.org/10.1097/01.NEP.0000000000000190

Sovacool, B. K., & Florini, A. (2012). Examining the complications of global energy governance. *Journal of Energy & Natural Resources Law, 30*(3), 235–263. https://doi.org/10.1080/02646811.2012.11435295

Stampery. (2022). Leaders in blockchain-based data certification. https://stampery.com/. Accessed 20 Nov 2022.

Sun, H., Wang, X., & Wang, X. (2018). Application of blockchain technology in online education. *International Journal of Emerging Technologies in Learning, 13*(10).

Suwal, S., Laukkanen, M., Jäväjä, P., Häkkinen, T., & Kubicki, S. (2019). Bim and energy efficiency training requirement for the construction industry. *IOP Conference Series: Earth and Environmental Science, 297*, 012037. https://doi.org/10.1088/1755-1315/297/1/012037

Swan, M. (2015). *Blockchain: Blueprint for a new economy*. O'Reilly

Tanaka, K. (2011). Review of policies and measures for energy efficiency in industry sector. *Energy Policy, 39*(10), 6532–6550. https://doi.org/10.1016/j.enpol.2011.07.058. sustainability of biofuels.

Underwood, S. (2016). Blockchain beyond bitcoin. *Communications of the ACM, 59*(11), 15–17. https://doi.org/10.1145/2994581

University, O.S. (2022). Your decentralized educational and professional identity. https://os.university/. Accessed 20 Nov 2022.

Woolf. (2022). Join the world's first global collegiate network. https://woolf.university/. Accessed 20 Nov 2022.

Yap, K. Y., Chin, H. H., & Klemeš, J. J. (2023). Blockchain technology for distributed generation: A review of current development, challenges and future prospect. *Renewable and Sustainable Energy Reviews, 175*, 113170. https://doi.org/10.1016/j.rser.2023.113170

Yousif, A. (2022). Blockchain: The protocol of value. https://bsvblockchain.org/news/blockchain-the-protocol-of-value/. Accessed 20 Nov 2022.