DOI: 10.38027/ICCAUA2021136N6

Exploring Blockchain in the Realm of a Network of Positive Energy Buildings

***** Dr. **Maurizio Sibilla** [1] , Dr. **George Blumberg** [2]
School of the Built Environment, Oxford Brookes University, United Kingdom [1 & 2]
E-mail [1]: msibilla@brookes.ac.uk , *E-mail [2]:* g.blumberg@brookes.ac.uk

Abstract
Positive Energy Blocks (PEBs) is a paradigm useful in the transition to a low carbon economy. This novel approach makes use the collective ownership of renewable energy generation and storage system to optimise their use. In addition to the networking of devices, PEBs also require a suite of managerial systems that can be used to integrate data with the network. One possible solution to this integration is by using Blockchain technology, which has the potential to resolve several issues in data management, security, and community integration. However, the use of Blockchains within PEBs has not been fully engineered or tested, and this paper presents the results of an exploration into possible solutions. The methods adopted in this research are descriptive and exploratory approaches in modelling a network of PEBs. This research points out how Blockchain technology would be used in the organisation process within a network of PEBs and would be useful for academics and professionals interested in delivering a new generation of buildings and services and in promoting collaborations.
Keywords: Energy Transition; Socio-technical approach; Built Environment; Positive Energy Buildings; Energy Communities.

1. Introduction

Cities are liable for 70% of the GHG emissions that cause global warming, although they cover only 3% of the world' territory (UN- Habitat, 2011). For this reason, the innovation of urban energy infrastructure has become a key action of the European Strategic Energy Technology Plan (SET-Plan) (EC, 2017). The SET-Plan takes into account a multitude of advanced low carbon technologies (e.g. nuclear, solar, wind, among others) in order to achieve the Paris Agreement target (i.e. to limit the global temperature increase to 1.5 C°) (UNFCC, 2015) and promote new competitive green economies.

However, only renewable energy sources can regenerate lost relationships between cities and communities. These relationships were typical of the pre-industrial era and dramatically mortified by the hegemony of fossil-fuel-based infrastructure, which is typically indifferent towards the local geographical conditions (Sibilla & Kurul, 2018). Nowadays, the high level of maturity achieved by renewable technologies (Masson et al., 2019), together with ICT advancements (Wu et al., 2018), has made the evolution from fossil and passive management infrastructure to renewable and interactive energy systems feasible.

These new typologies of infrastructure have not been codified yet. The literature presents different concepts such as active buildings (Fosas et al., 2021), positive energy blocks (Blumberga et al., 2020), positive energy districts and energy communities (Seyfang et al., 2014), which are the new paradigms on which the energy policies and practices in Europe are being developed (EU, 2018). The common factors among these new paradigms are that some buildings can produce more energy that consume, offering an opportunity to active a peer-to-peer energy exchange (Sibilla & Manfren, 2021). For example, a positive energy block refers to the interconnection of at least three buildings, and it is considered a preliminary step towards a self-organised energy community. In such a scenario, a multitude of actors who act as prosumers appears. As stressed by Manfren et al. (2021) it is expected that these local actors will use the distribution grid to share power directly with their neighbours. In this regard, developing distributed approaches to enhancing energy sharing among local renewable energy communities is critical for large-scale implementation of such self-organised energy community.

Therefore, this study is motivated by the realisation that fundamental to the transition to a low-carbon energy infrastructure is a devolution from large, centralised power generation to smaller, local networks that use renewable energy sources. For newly built and redeveloped urban complexes, this transition implies multiple owner-organisations that may be a mixture of consumers, producers, and custodians (i.e., for storage) of energy. These distributed renewable and interactive energy systems (DRIESs) are composed of PEBs nets, and thus, they are a web of closely located devices where a range of energy types are produced, consumed, and stored. Despite the requirement to overturn more than a century of established commercial conditions, this is seen as an essential part of the process in shifting from fossil fuel to low carbon energy. These largely decentralised and small-scale systems require the reworking and reinvention of the entire supply chain and this in turn demands more interactive and democratised management. For example, engagement with the local community (or consumer base) is intensified as the ratio between producers and consumers converges towards parity. A new suite of knowledge is required to design, deploy, and maintain the new infrastructure required by PEBs nets.

However, establishing PEBs as a common practice requires the development of appropriate tools to allow local actors to exchange energy within a shared regulatory framework. Technological innovation is a key factor to drive the energy transition. For example, smart grid integrated with ICT has allowed users to control the bi-directional energy and financial flows (Camarinha-Matos et al., 2016). In addition, a new generation of business models and policies has supported the affirmation of liberalised energy markets. However, as pointed out by Ahl et al. (2020) small-scale trading, on the other hand, is limited by regulatory standards and transaction costs that outweigh the benefits. License specifications, for example, are still a barrier to small-scale prosumer market participation. The number of prosumers is likely to grow, necessitating changes in exchange structures, market access, and grid stability.

In this regard, blockchain technology is a possible solution. However, how blockchain-based energy systems can contribute the low carbon transition is an open issue. Several recent studies have emphasised blockchain technology opportunities to manage energy and information flows (e.g. Petri et al. 2020; Farnaghi & Masourian, 2020; Allam & Sydney Jones, 2019). Petri et al. (2020) highlighted that blockchain would make it easier for local actors to participate in the shared economy by allowing them to move between multiple business offerings with greater ease. Farnaghi et Masourian (2020) explored the blockchain applications in urban planning, integrating the blockchain technology with web-based public participatory GIS to make more open and transport the public participation in decision-making processes. Allam and Sydney Jones (2019) developed a new model for preventing urban sprawl by promoting the trading of time-sensitive air rights through Smart Contracts on the Blockchain.

Hence, the examples above-mentioned have demonstrated the increasing dissemination of blockchain as a reliable technology and the broad fields of application and impacts that such a technology can have on the transition towards a low carbon society. Specifically, this technology can play a key role in operationalising PEBs, which in turn affects the way we design buildings and cities. Therefore, greater attention towards this technology is needed, to consolidate the role of the built environment professionals (architects, urban designers, planners, and engineering, among others) as intermediaries of the energy transition.

Within the interdisciplinary arena of the 4th International Conference of Contemporary Affairs in Architecture and Urbanism, this paper explores the concept of Blockchain and its relationships with the emerging paradigm of distributed renewable and interactive energy system as a strategy to compose PEBs. This is an exploratory study aimed at introducing the concept of the Blockchain. Therefore, the paper is organised as follows: Section 2 presents blockchains as a feature in a renewable energy microgrid**.** Then (Section 3) briefly describes the blockchain architecture. Finally, implications in adopting blockchain for PEBs are discussed.

2. Blockchains as a Feature in Positive Energy Blocks

This section describes blockchains as a tool to manage data in PEBs. The blockchain is best known as the enabling technology for crypto currencies, but equally interesting uses in the Built Environment is for enabling autonomy in data collection within smart cities and the management of data within distributed renewable energy microgrids. Some features concerning blockchain technology are illustrated in the following sub-sections.

2.1. Distributed Systems and Blockchains Technology

To illustrate the challenges of managing data within energy PEBs, a schematic of a typical system is shown in Figure 1. This schematic includes typical devices that can be used for the generation, storage, and consumption of various forms of energy.

Blockchains are a platform technology that have many potential uses. The best way to understand how they work and what they are good for is to describe the technology behind the blockchains and what applications they are useful for. They provide novelty by their ability to hold critical data that, once written, are immutable, protected, and can reside on a distributed network of computers. Immutability provides the data with authenticity; the use of distributed networks allows independence of a central hosting authority. Berg, et al., (2018) described blockchains as a modern version of a paper ledger. Zheng, et al., (2018) and Pilkington, (2016) proposed applications of blockchains beyond their original use of cryptocurrency. Zheng, et al., (2020) provide an overview of smart contracts, small pieces of computer code that are embedded in the blockchain, that can help automate processes. Perhaps the greatest feature of blockchains is that they enable mutually distrustful parties to transact safely without the intervention of a trusted third party (such as a bank). They are therefore a mechanism that institutionalizes trust (see Werbach, 2018).

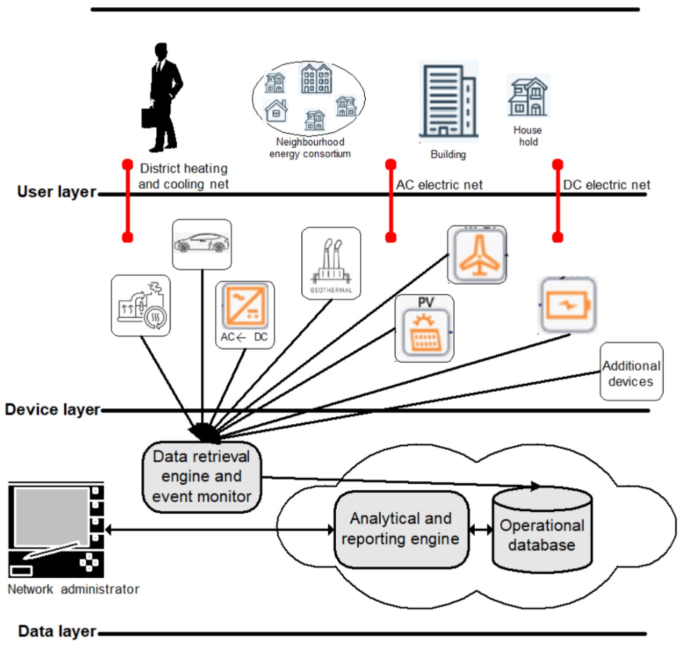

Figure 1. The figure contains a model of PEBs showing three organisational layers: data, device and user.

These features and capabilities are increasingly in demand as mobile arrays of interconnected devices produce volumes of data that can be valorised by artificial intelligence, big-data analytics, and advanced visual displays. Other proponents of blockchain technology have been quick to propose applications to support concepts in the built environment such as for data security in the Internet of Things (IoT) (Delgado-Mohatar, et al., 2020; Panarello, et al., 2018) and for smart cities (Huckle, et al., 2016) as a security backbone for Industry 4.0 (Lee, et al., 2019), , as an element in digital twins used to promote traceability, compliance, authenticity, quality, and safety (Yaqoob, et al., 2020), in edge computing (Xiong, et al., 2018), and for BIM. What all these concepts require is reliable machine to machine communications, such as those described by Afanasev, et al., (2018) on a secure data-layer that is able to overcome the segmentation caused by multiple sources.

Of particular relevanceis the work of Devine & Cuffe (2019), who describe a blockchain-based system that facilitates transactions on a smart grid where energy is traded using energy-backed tokens that can be redeemed by users.

For simplicity, applications involving blockchains can be divided into two broad categories:

- for holding critical information such as certificates, authorisations, payments, debt obligations and cryptocurrency;
- and for enacting smart contracts to provide data management within complex trading environments.

Both classes of applications make use of the same core engineering elements as those in cryptocurrencies, but have added capabilities that allow for smart contracts and a choice of algorithms for ordering and confirming the authenticity of the data. Thefore, blockchains achieve their unique characteristics by the application of three technologies. These are: cryptography, distributed systems on networks, and consensus algorithms.

2.1.1. The use of Cryptography in a Blockchain

The combined use of cryptograpy, a consensus mechanism and distributed systems provides the blockchain with the attribute of immutability. In its most basic form, a blockchain is a computer file that resides as exact copies in multiple nodes of a computer network. An example of a fragment of a blockchain file is shown in **Error! Reference source not found.**.

In this diagram, the three large vertical rectangles represent the *blocks* from which the blockchain derives its name. At the core of the blockchain is the cryptographic hash function (CHF), a mathematical algorithm that is very useful as it converts data of an arbitrary size (for example, a message or a password) to a string (or *hash*) of a fixed length. There are no passwords involved and, as a one-way (i.e., irreversible) function, it is nearly impossible to un-hash the data. Hashes have useful properties, for example, miniscule difference in the original text makes for significant differences in the hashed versions.

The CHF is used to ensure that the chain of records contained in a blockchain cannot be altered as it would interfere with the propagation of hashes that are used to link one block to the next. An example of this is shown in the sixteen-digit hexadecimal hash (representing 64-bit encryption) shown in **Error! Reference source not found.**. In addition to the hash of the previous block, each block also contains a schema referred to as the Merkle Tree (not shown in **Error! Reference source not found.**), a structure in which historic hashed data are stored.

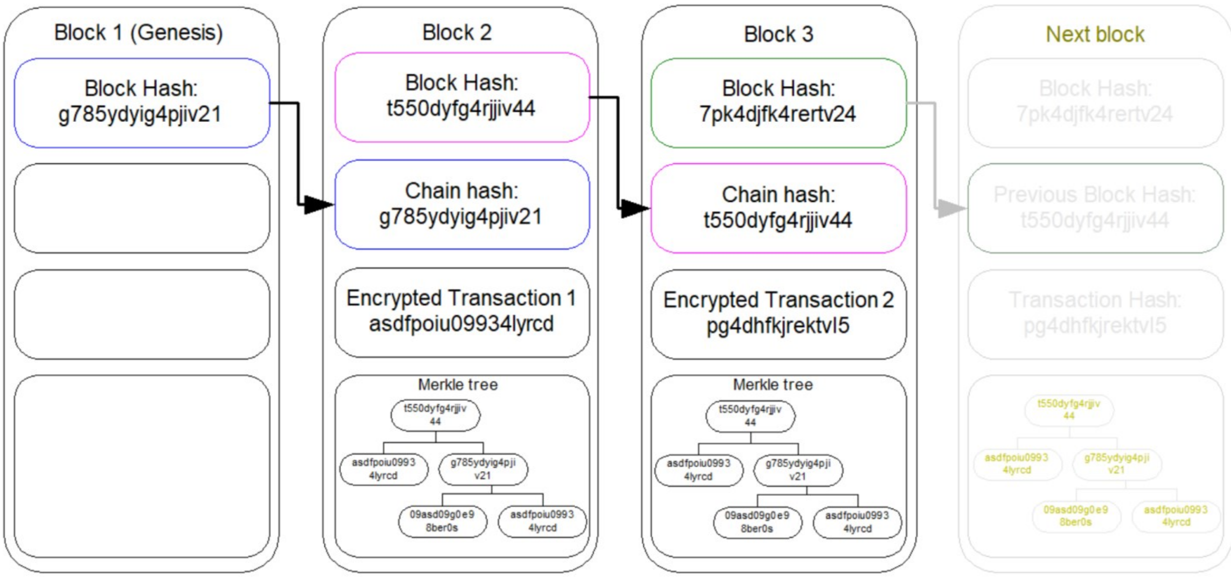

Figure 2. The figure contains a schematic diagram of a typical blockchain file.

Cryptography, in the form of *asymmetrical key* (see Singh, 2000), is used elsewhere on the blockchain to ensure the security and privacyof individual record. This helps protect against attempts to alter the details of the records as is required by current standards for computer security in the built environment. Users are issued with a unique pair of numbers by a trusted certificate authority (CA). One – the private key – is kept secret, while the other, the so-called public key, is visible to all. The public key of the pair is used to encode a message that can only be decoded with the private key, thus ensuring a level of individually tailored privacy on the data in a shared ledger or blockchain.
Error! Reference source not found. illustrates how the blockchain file is constructed, but to determine which records are permitted to be written to the blockchain requires the use of an ordering and consensus algorithm.

1.2.2. Use of Smart Contracts in Blockchains for Data Management in Positive Energy Blocks

The second technology needed in a blockchain is the ordering and consensus algorithm, the main purpose of which is to ensure only legitimate records get added to the blockchain and that they are added in the correct order. This is necessary as information can be submitted to the blockchain via any of the nodes in the network and once accepted as a legitimate entry, must be propagated to every copy of the blockchain that exists on the network.
For cryptocurrencies, like bitcoin, the most common form of consensus algorithm is proof-of-work, a time and energy intensive operation where self-selected members of the network race to perform a routine that confirms the authenticity and order of the transactions. In these blockchains, there can be thousands of nodes, each with their own copy of the blockchain and each recording thousands of transactions per hour. Members who do the computation the fastest are rewarded with cryptocurrency credits.
Fortunately, the PoW algorithm is not required for industrial blockchains, such as those designed for C&E projects. In these systems, the number of traders is likely to be less than one hundred and a transaction rate less than a hundred per day. In these cases, the ordering and consensus algorithm must ensure that basic trading rules are enforced between members and that the transactions are legal. For example, as those confirmed as legitimate by adhering to pre-determined set of requirements, such as a digital signature or a pass code. An effective consensus algorithm will reduce the ability to fake, falsify or enter a transaction more than once. In real trading environments, this double entry can be costly and seen as hallmarks of organized crime (Beare 2007, p.43).
More importantly the system must be robust and dependable. This can be achieved by incorporating the so-called *Byzantine fault tolerance* (BFT as first described by Lamport et al., 1982) ordering and consensus algorithm. Using BFT, there is an added level of security as data us preserved even if one or more of the nodes goes out of service during operations.

2.2.3. Distributed Systems, Consensus, and Ordering

Distributed systems are the final technology that makes workable. Blockchains exist only because they can be shared by nodes across a network using a peer-to-peer application. Key to these working is, of course, the internet, which provides the language and physical systems that permits communication and coordination. Two additional concepts are described in this section, that of the algorithms for arriving at consensus and ordering (See Steinmetz & Wehrle (2005) for an in-depth explanation of peer-to-peer system and Wang et al., (2018) for a comparison and discussion of consensus algorithms.

To illustrate these concepts further, consider the diagram in **Error! Reference source not found.**. This flowchart maps the transactions of an *asset* between members of a trading network (referred to as *Nodes* in this example). The *asset* traded could be any entity that is able to be represented by digital data, for example, a quantity of material, a confirmation of delivery or a building component.

The initiation of the network starts when Peer node 1 establishes the network and performs a series of tasks, such as setting up a certificate authority for public/private key encryption on the network. This closed, permissioned network is represented by the central octagonal box. In this scenario, the system administrator also sets up a world state database, configures the consensus algorithm and invites members to join the network. This action is represented by the arrow labelled **A** in the figure. The act of establishing a network starts the process where transactions can be recorded. Trading records are sent to the Peer nodes (represented by the arrow labelled **B**) for confirmation via a network consensus and protocol to create the Genesis block. The arrow labelled **C** shows Peer Node 3 writing two separate transactions to the network. Included in this newly written Block 2 includes the hash of the previous block. Block 2 is created only after it has been confirmed and verified by the consensus algorithm. This is shown by the arrow labelled **D**. This process is repeated when Peer node 1 sends 2 transactions to peers to await the creation of Block 3 (**E**). This, in turn, includes the hash of the previous Block 2, again only after consensus confirmation has been confirmed (**F**). At each stage of this process, the nodes within the network contain identical versions of the blockchain file and will continue to do so until the next transaction is proposed.

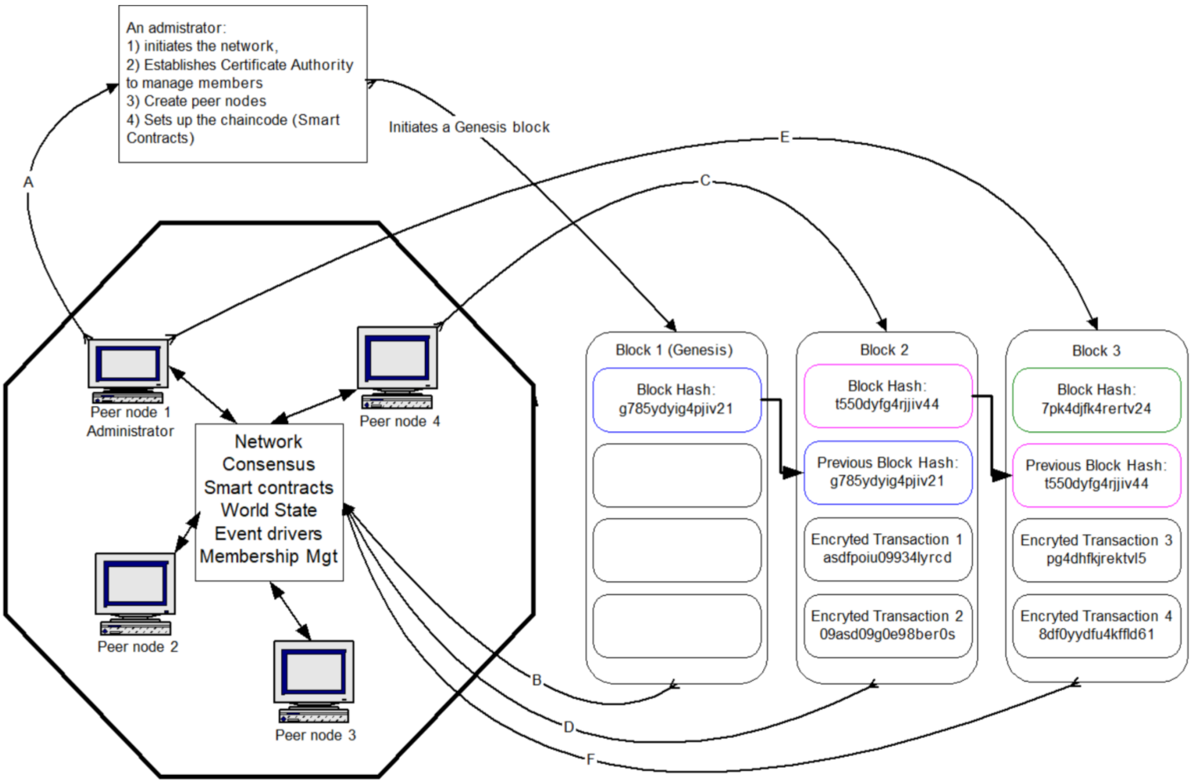

Figure 3. This diagram shows a simplified schematic of how the core the blockchain relies on a network of computer sot function properly. A flowchart describes how transactions are recorded on a blockchain. In this diagram, where arrows show the direction that records are written by individual nodes in the network, then agreed upon and distributed to the other nodes on the network.

2.3. Data Integration and Analysis

The critical aspect of the potentially large and complex energy network is that the data from individual sources are effectively separated into so-called *data silos*. They need to be combined into a single useable database to make them useful for engineering purposes, such as system diagnostics or for commercial reasons, such as payment and receipts. Data are further complicated as individual units (generation, consumption, or storage) have unique characteristics. For example, they might not in the same format, so preparation and calibration are necessary. In any real system, individual devices must be identified with an indexable model number so that readings can be normalised.

The device data, which contains energy generation as well as other useful information, will require post-collection processing and in some case, calculations. Some of the complexity inherent in data management is that some devices are a combination of a producer, consumer and as a storage for energy. For example, an electric car that

has photovoltaic cells on the roof and a large storage capacity can act, when connected to the network, act as producer, consumer and as storage for electrical energy. Calculations are required for a range of essential energy accounting activities, for example the setting of the chargeable rate for energy produced, consumed, or stored by a device and how this rate changes with time. As all energy generation are associated with carbon production. If accounting takes this into account, each device would require separate calibration and normalisation.
The design of this system has a bearing on the data management for energy production, consumption and storage which would be engineered to link to extend to other networks, including the national energy *maxigrid*.

2.4. Business Models for Renewable Energy Microgrids
The reason why devices require post-collection processing is that there are multiple organisations operating within the grid. These include housing developments, university campuses, neighbourhood green energy collectives as well as individual producer-consumers.
Ultimately, the success in setting up PEBs relies on attracting capital for investment for devices and the infrastructure through which energy is transferred. Establishing commercial arrangements – the so-called *business model* – is particularly relevant during the planning and design phases, when developers build a partnership of investors, residents, and other stakeholders. Such partnership building is an essential component of the energy strategy and, if successfully articulated, could aid in achieving sustainability qualifications for the development.
The business model requires accurate data management as well as flow and process analytics. Reliable calculation of meter readings is required for individual devices so that appropriate credit or debit can be granted to their respective owners. There is abundant opportunity for falsification of data as well as systematic errors in energy accounting that could have potentially damaging impact on commercial relations within the network.
The software used in design allows engineers to determine the best resource mix to develop a cost-effective strategy that would include such features as a demand charge reduction, some way to do energy arbitrage and to design an optimised system that would deliver to the community the best rate of return for their investment.
An example of one such partnership would be a neighbourhood energy consortium formed by residents who, orchestrated by the developer, band together to invest in an array of renewable energy devices connected to the network. Members of the consortium would benefit from their investment by having preferential access to low-cost, renewable energy and, if there was any excess, to sell it back to the network. Other partnership agreements could be reached by building owners who would include renewable energy as part of their corporate sustainability planning.
Fortunately, impediments to the smooth adoption of this new technology, notably in scaling up in size and in managing the networks are being removed as leading technology companies now offer blockchain hosting and partnering solutions and by a swarm of start-up companies who are producing innovative technology that makes programming easier.
This model is dependent upon the capacity to invite new members that could join in the network if their devices were compatible with the network and that they would fit into the overall system design.
The purpose of the business model for use in the management of device information is required energy pricing, reconciliation, and financial and environmental reporting. Obtaining useful services from any data management technology requires that the business process is mapped out and codified.

3. Digital Blockchains Architecture
Figure 4 shows the basic system architecture of the blockchain technology that includes the administrator and developer, smart contracts, database, peers, and events based upon the HLF implementation. Peers are identified by the symbol 'P'. This architecture includes the following elements:

- **Item 1:** A system administrator that can design and establish the initial configuration of the system, manage deployment of smart contracts, define, and set the endorsement, configure the consensus and ordering algorithm, invite members and ensure that the integrity of the data is maintained in a secure private server.
- **Item 2:** An ordering and consensus algorithm to manage the recording of accepted transactional data to the blockchain and to be able to convert sequential data to a more convenient relational format so that is can be used to write reports and other structured documents that are necessary for operational purposes (such as reconciliation, invoicing, and general accounting).
- **Item 3:** Maintain the peer network, through membership recruitment, so that they can hold copies of the distributed ledgers and associated smart contracts.
- **Item 4:** Implement and maintain an events management system as a modular component of the DLT to provide communication and notification.
- **Item 5:** Ensure that a suitable cloud service is maintained so that it can perform the role of a secure data and system repository.

The systems administrator, shown near the top of **Error! Not a valid bookmark self-reference.**4 has the responsibility for the deployment and administration of the blockchain technology, which may include multiple channels. These are essential in allowing trading partners to maintain privacy. This protects confidential commercial data but would still allow mission-critical information such as the delivery date, warranty details and maintenance instructions, to be made available for a wider audience. Including in this figure is a representation of a relational database, which is accessed with the standard query language (SQL).
What is not shown in **Error! Not a valid bookmark self-reference.** are some of the finer features of the blockchain technology,notably how the consensus algorithm works, and the way that smart contracts are embedded into the core of the blockchain, or how the interface uses pull-down menus, check boxes and other forms of browser-based tools.

4. Conclusion: Towards Positive Energy Blocks and Self-organised Energy Communities

This exploratory study focused on some features of blockchains technology as a tool to put the paradigm of PEBs and self-organised energy communities into practices. The most important feature is that members of the local communities can produce and exchange energy locally. In this regard, this study has stressed the importance to re-organise the energy supply chain and introduce appropriate advanced tools to manage these energy exchanges, presenting the blockchain technology as a possible solution.
First of all, blockchain is a tool to build a community of users for open market energy. According to Ferreira and Martins (2018) big energy companies still dominate the market. As a result, the economic benefits for the prosumers are restricted. By contrast, a blockchain platform able to manage transaction within a net of PEBs allows prosumers to act as key enablers for the organisation of an energy community, guarantying transparency, accountability, integrity and promoting new business opportunities.
This study is in line with Maria-Lluïsa Marsal-Llacuna (2018), who stressed the need to conduct research focused on blockchain applications at the urban scale to investigate the role of blockchains technology in delivering new decentralised and citizen-centric approach in urban governance. Indeed, affirming self-organised energy communities as a common practice means to enhance the role and responsibility of citizens in shaping a low carbon society rather than to delegate the transition to the central authority. By doing so, local communities' physical and social organisation become a synchronised component of a such transition. In this regard, blockchain's bottom-up mechanism may be an alternative approach in delivering codes to operationalise self-organised energy communities. However, in agreement with Khatoon et al. (2019), while blockchain technology can be considered as an additional step towards the affirmation of a reliable digital transaction platform; what will be the role of different stakeholders in the future energy market is an open issue, and several barriers must be overturned.
As pointed out by Andoni et al (2019), blockchain applications refer to small-scale projects that are still in an early development phase. Therefore, scalability is one of the most relevant barriers. On the one hand, transactions must be secure; on the other hand, they must be fast. Thus, dedicated energy web blockchain platforms are being developed (e.g. https://www.energyweb.org/), which can scale up to thousands of transactions per second.However, future research is focused on coding new algorithms in order to avoid malfunctions when the technology is applied at scale.
Another significant barrier is the national regulatory framework. In Europe, through the directive dedicated to the energy communities (i.e. RED II 2018/2001/EU), citizens can produce and exchange energy locally. Each European Counties has started to ratify the EU directive and develop its own concept concerning self-organised energy communities. In Italy, for example, citizens can create a consortium to manage a power plant of 200 kW. This is a great step toward the affirmation of renewable technologies, and blockchain technologies can sustain such process. However, the current regulatory framework should be updated in order to take into account the opportunity offered by a blockchainstechnology. The inclusion of blockchain technologies into the existing regulatory framework allow policymakers to promote large scale applications and develop standardization and flexibility measures.

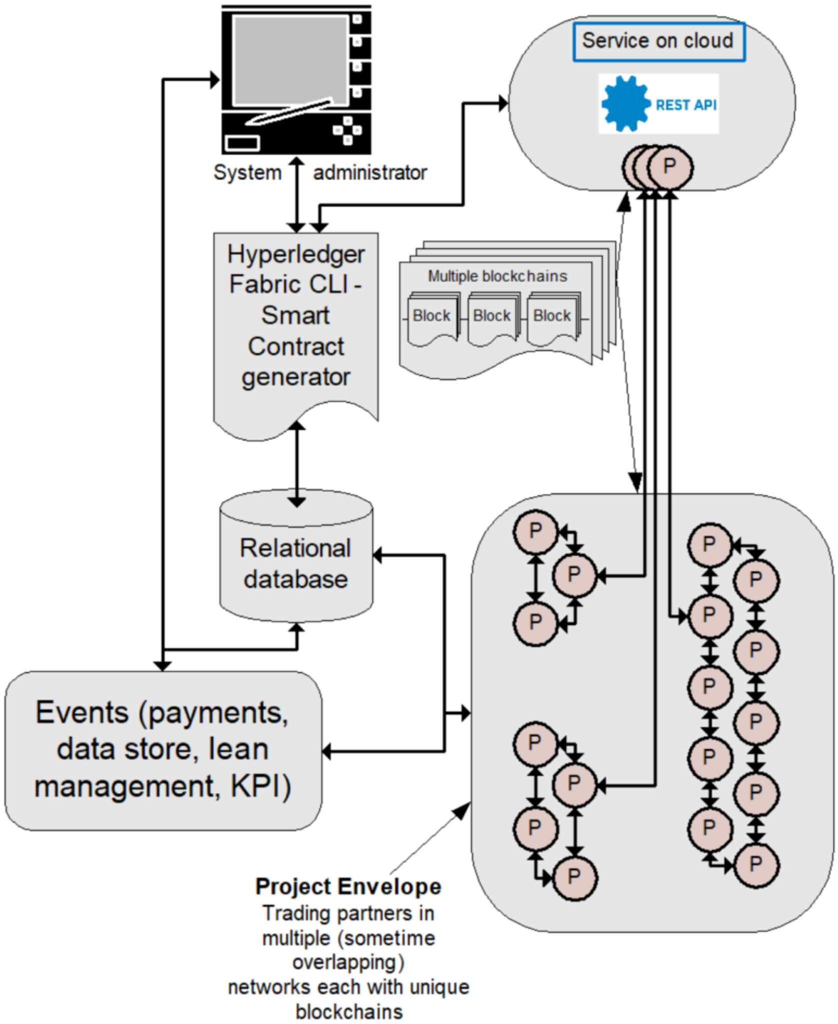

Figure 4. Basic system architecture of the blockchain technology.

In conclusion, the scenario centred on a net of PEBs refers to the key role of energy communities which, require appropriate tools and procedure to act as manager of a distributed network of energy nodes. However, while the energy community concept is not new, a new generation of self-organised energy communities is emerging. This new typology will try, for the first time, to work as a whole. In other words, different actors with a multiple set of objectives will work in synchrony thanks to the advanced ICT platforms. Blockchains technology is part of this scenario, allowing local actors to manage energy and information flows in real time. By doing so, blockchain technologies may contribute to making a net of PEBs a reliable and feasible energy infrastructure.

Acknowledgement
This study was supported by the Oxford Brookes' Research Excellence Award 2020-21.

Conflict of interests
The authors declare no conflict of interest.

References

Ahl, A., Yarime, M., Goto, M., Shauhrat S. Chopra, Nallapaneni Manoj. Kumar, Tanaka K. & Sagawa, D. (2020).Exploring blockchain for the energy transition: Opportunities and challenges based on a case study in Japan. *Renewable and Sustainable Energy Reviews,* 117:109488. https://doi.org/10.1016/j.rser.2019.109488

Afanasev, M.Y., Fedosov, Y.V., Krylova, A.A. & Shorokhov, S.A. (2018). An application of blockchain and smart contracts for machine-to-machine communications in cyber-physical production systems. In Proceedings of the IEEE Industrial Cyber-Physical Systems (ICPS), 13–19

Allam, Z. & Sydney Jones, D. (2019). The Potential of Blockchain within Air Rights Development as a Prevention Measure against Urban Sprawl, *Urban Science*, 3(1):38. doi:10.3390/urbansci3010038

Andoni, M., Robu, V., Flynn, D., Abram, S., Geach, D., Jenkins, D., McCallum, P., Peacock, A. (2019). Blockchain technology in the energy sector: A systematic review of challenges and opportunities. Renewable and *Sustainable Energy Reviews,* 100, 143–174. https://doi.org/10.1016/j.rser.2018.10.014

Beare, M. E. (2007). The devil made me do it: business partners in crime. *Journal of Financial Crime*, 14(1):34-48. https://doi.org/10.1108/13590790710721792

Berg, C., Davidson, S. ,& Potts, J. (2018). Ledgers. Available at SSRN: http://dx.doi.org/10.2139/ssrn.3157421

Blumberga, A., Vanaga, R., Freimanis, R., Blumberga D.,, Antužs, J., Krastiņš A.,, Jankovskis, I., Bondars, E. & Treija, S. (2020). Transition from traditional historic urban block to positive energy block, *Energy*, 202: 117485. https://doi.org/10.1016/j.energy.2020.117485

Camarinha-Matos, LM. (2020). Collaborative smart grids – A survey on trends. *Renew Sustain Energy Rev*, 65:283–94. https://doi.org/10.1016/j.rser.2016.06.093

Delgado-Mohatar, O., Tolosana, R., Fierrez, J., & Morales, A. (2020). Blockchain in the internet of things: Architectures and implementation. *IEEE 44th Annual Computers, Software, and Applications Conference,* 1072-1077. doi: 10.1109/COMPSAC48688.2020.0-131

Devine, M. T. & Cuffe, P. (2019). Blockchain electricity trading under demurrage. *IEEE Transactions on Smart Grid*, 10(2):2323-2325. doi: 10.1109/TSG.2019.2892554

European Commission. (2017). Strategic energy technology Plan. Directorate-general for research and innovation.

EU. (2018). European Parliament, Directive 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (Dec. 2018). http://data.europa.eu/eli/dir/2018/2001/oj/eng

Farnaghi M., & Masourian A. (2020). Blockchain, an enabling technology for transparent and accountable decentralized public participatory GIS, *Cities* 105:102850. https://doi.org/10.1016/j.cities.2020.102850

Fosas, D., Nikolaidou E., Roberts M., Allen S., Walker I. & Coley D. (2021). Towards active buildings: Rating grid-servicing buildings, *Building Serv. Eng. Res. Technol*, 42(2), 129-155. DOI: 10.1177/0143624420974647

Huckle, S., Bhattacharya, R., White, M., & Beloff, N. (2016). Internet of Things, Blockchain and Shared Economy Applications, *Procedia Computer Science,*98, 461-466. https://doi.org/10.1016/j.procs.2016.09.074

Khatoon A., Verma P., Southernwood, J., Massey, B., & Corcoran, P. (2019). Blockchain. Energy Efficiency: Potential Applications and Benefits. *Energies*, 12, 3317. doi:10.3390/en12173317

Lamport, L., Shostak, R., & Pease, M. (1982). The byzantine generals problem*. ACM Transactions on Programming Languages and Systems* (TOPLAS), 4(3):382-401. https://doi.org/10.1145/357172.357176

Lee, J., Azamfar, M., & Singh, J. (2019). A blockchain enabled cyber-physical system architecture for Industry 4.0 manufacturing systems. *Manufacturing Letters*, 20:34-39. https://doi.org/10.1016/j.mfglet.2019.05.003Get

Manfren, M., Sibilla, M. & Tronchin, L. (2021). Energy modelling and analytics in the built environment– A review of their role for energy transitions in the construction sector. *Energies*, 14(3), 679. https://doi.org/10.3390/en14030679

Marsal-Llacuna, ML. (2018). Future living framework: Is blockchain the next enabling network? *Technological Forecasting & Social Change* , 128, 226–234. https://doi.org/10.1016/j.techfore.2017.12.005

Masson, G., Kaizuka I., Detolleanere, A., Lindahl, J., Jäger-Waldau A. (2019). Snapshot of Global PV Markets, Tech. rep., IEA PVPS.

Panarello, A., Tapas, N., Merlino, G., Longo, F., & Puliato, A. (2018). Blockchain and IoT integration: A systematic survey. *Sensors*, 18(8), 2575. https://doi.org/10.3390/s18082575

Petri, I., Barati, M., Rezgui, Y. & Rana O.F..(2020). Blockchain for energy sharing and trading in distributed prosumer communities. *Computers in Industry,* 123, 103282. https://doi.org/10.1016/j.compind.2020.103282

Pilkington, M. (2016). Blockchain technology: principles and applications. In F. Xavier Olleros, M. Z., editor, Research Handbook on Digital Transformations, volume 225, chapter 11. Edward Elgar Publishing, Cheltenham, Gloucestershire, GL50 2JA, UK.

Seyfang, G., Hielscher, S., Hargreaves, T., Martiskainen, M., Smith, A.. (2014). A grassroots sustainable energy niche? Reflections on community energy in the UK. *Environmental Innovation and Societal Transitions,* 13 (2014), 21–44. https://doi.org/10.1016/j.eist.2014.04.004

Sibilla, M., & Kurul, E. (2018). Distributed Renewable and Interactive Energy Systems in Urban Environments. *TECHNE Journal of Technology for Architecture and Environment*, special series 1, 33-39. https://doi.org/10.13128/Techne-22710

Sibilla M., & Manfren, M. (2021), Envisioning Building-as-Energy-Service in the European context. From a literature review to a conceptual framework, Architectural Engineering and Design Management, DOI: 10.1080/17452007.2021.1910924

Singh, S. (2000). The Code Book: The Science of Secrecy from Ancient Egypt to Quantum Cryptography. Fourth Estate, London

Steinmetz, R. & Wehrle, K. (2005). Peer-to-peer systems and applications, Lecture Notes in Computer Science, volume 3485 Springer.

UN habitat. (2012). Hot cities: battle-ground for climate change CHANGE, Glob. Rep. Hum. Settl., 2, 1-2 UNFCC. 2015. Paris Agreement.

Wang, W., Hoang, D. T., Xiong, Z., Niyato, D., Wang, P., Hu, P., & Wen, Y. (2019). A survey on consensus mechanisms and mining management in blockchain network. *IEEE Access*, 7, 22328-22370. doi: 10.1109/ACCESS.2019.2896108

Werbach, K. (2018). The blockchain and the new architecture of trust. MIT Press, Cambridge, Massachusetts

Wu, J., Tran N., (2018). Application of blockchain technology in sustainable energy systems: An overview. *Sustainability,* 10:3067. https://doi.org/10.3390/su10093067

Xiong, Z., Zhang, Y., Niyato, D., Wang P. & Han Z. (2018). When Mobile Blockchain Meets Edge Computing. *IEEE Communications Magazine*, 56(8), 33-39. doi: 10.1109/MCOM.2018.1701095

Yaqoob, I., Salah, K., Uddin, M., Jayaraman, R., Omar, M., & Imran, M. (2020). Blockchain for digital twins: Recent advances and future research challenges. *IEEE Network*, 34(5):290-298. doi: 10.1109/MNET.001.1900661

Zheng, Z., Xie, S., Dai, H.N., Chen, X., & Wang, H. (2018). Blockchain challenges and opportunities: a survey. *International Journal of Web and Grid Services*, 14(4):352-375.

Zheng, Z., Xie, S., Dai, H.-N., Chen, W., Chen, X., Weng, J., & Imran, M. (2020). An overview on smart contracts: Challenges, advances and platforms. *Future Generation Computer Systems*, 105:475-491. https://doi.org/10.1016/j.future.2019.12.019