ANKARA YILDIRIM BEYAZIT UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

INTEGRATING BLOCKCHAIN IN SMART BUILDING SYSTEMS: A FRAMEWORK FOR EFFICIENCY AND SCALABILITY

M.Sc. Thesis by

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November, 2024

ANKARA

INTEGRATING BLOCKCHAIN IN SMART BUILDING SYSTEMS: A FRAMEWORK FOR EFFICIENCY AND SCALABILITY

A Thesis Submitted to

The Graduate School of Natural and Applied Sciences of

Ankara Yıldırım Beyazıt University

In Partial Fulfillment of the Requirements for the Degree of Master of Science in the Faculty of Fine Arts and Architecture, Department of Architecture

by

Duygu SAVUR

November, 2024

ANKARA

M.Sc. THESIS EXAMINATION RESULT FORM

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ACKNOWLEDGMENTS

First and foremost, I would like to extend my deepest gratitude to my beloved family for their unwavering support and encouragement throughout every stage of my life and academic journey. I am especially grateful to my supervisor, Assoc. Prof. Dr. Şeyda Emekci, for her invaluable guidance, insightful suggestions, and continuous motivation during the course of my research. Her profound knowledge and thoughtful recommendations have played a pivotal role in shaping this study. I also wish to express my sincere appreciation to my friends, whose unwavering support and encouragement provided me with strength and perseverance throughout this process.

2024, 21 November **Duygu SAVUR**

INTEGRATING BLOCKCHAIN IN SMART BUILDING SYSTEMS: A FRAMEWORK FOR EFFICIENCY AND SCALABILITY

ABSTRACT

The continuous development of humanity has resulted in the emergence of new needs and solutions, with the Industrial Revolution representing a pivotal turning point. This has heightened the significance of energy management, particularly within the construction industry, which is a significant consumer of energy. In the absence of effective energy management, there has been a notable increase in environmental and economic risks.

In this context, smart building systems based on sensor data and internet connectivity have emerged. However, these present new challenges, including data storage and security. It is therefore crucial to ensure the secure storage and processing of data obtained from sensors in order to enhance the effectiveness of smart building. Blockchain technology has the potential to enhance the efficiency of energy management by ensuring the secure and transparent storage of data in a decentralised structure. This study aims to examine the solutions to prominent problems in smart buildings by weighing the solutions to blockchain technology with the Analytical Network Process method. Furthermore, it will discuss how blockchain technology can be used in data processing and security issues in smart buildings by combining these two concepts.

The study is based on the keywords 'blockchain technology' and 'smart building' in the literature. In order to evaluate the recommendations derived from the literature analysis, the laboratory building is taken as a case study. This approach is intended to provide feasible solutions for data integration, security and decentralised management of smart buildings in energy management.

Keywords: Blockchain technology, energy, smart building

BLOK ZİNCİR TEKNOLOJİSİNİN AKILLI BİNA SİSTEMLERİNE ENTEGRASYONU: VERİMLİLİK VE ÖLÇEKLENEBİLİRLİK İÇİN BİR ÇERÇEVE

ÖZ

İnsanlığın sürekli gelişimi, Sanayi Devrimi'nin önemli bir dönüm noktası olmasıyla birlikte yeni ihtiyaçlara ve çözümlere yol açmıştır. Bu durum, özellikle büyük bir enerji tüketicisi olan inşaat sektöründe enerji yönetiminin önemini artırmıştır. Etkin bir enerji yönetimi olmadan, çevresel ve ekonomik riskler önemli ölçüde artmıştır.

Bu bağlamda, sensör verilerine ve internet bağlantısına dayalı akıllı bina sistemleri ortaya çıkmıştır. Ancak bunlar veri depolama ve güvenlik gibi yeni zorlukları da beraberinde getirmektedir. Bu nedenle, akıllı binaların etkinliğini artırmak için sensörlerden elde edilen verilerin güvenli bir şekilde depolanmasını ve işlenmesini sağlamak çok önemlidir. Blok zinciri teknolojisi, verilerin merkezi olmayan bir yapıda güvenli ve şeffaf bir şekilde depolanmasını sağlayarak enerji yönetiminin verimliliğini artırma potansiyeline sahiptir. Bu çalışma, Analitik Ağ Süreci yöntemi ile blok zinciri teknolojisine yönelik çözümleri tartarak akıllı binalarda öne çıkan sorunlara yönelik çözümleri incelemeyi amaçlamaktadır. Ayrıca bu iki kavramı birleştirerek akıllı binalarda veri işleme ve güvenlik konularında blokzincir teknolojisinin nasıl kullanılabileceğini tartışacaktır.

Çalışma, literatürde yer alan ‘blokzincir teknolojisi' ve 'akıllı bina' anahtar kelimelerine dayanmaktadır. Literatür analizinden elde edilen önerileri değerlendirmek için laboratuvar binası bir vaka çalışması olarak ele alınmıştır. Bu yaklaşımın, enerji yönetiminde akıllı binaların veri entegrasyonu, güvenliği ve merkezi olmayan yönetimi için uygulanabilir çözümler sunması amaçlanmaktadır.

Anahtar Kelimeler: Akıllı binalar, blokzincir teknolojisi, enerji

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NOMENCLATURE

Blockchain Technology

BC	Blockchain
BCT	Blockchain Technology
CoAP	Constrained Application Protocol
DLT	Distributed Legendre Technology
P2P	Peer-to-Peer
PoW	Proof of Work
TSS	Trust-based Security System

Smart Building

BEM	Building Energy Management
BEP	Building Energy Performance
BMS	Building Management System
CBEMS	Conventional Building Energy Management Systems
CTES-SB	Context-Based Evaluation System- Smart Building
EV	Electric Vehicle
HVAC	Heating, Ventilating and Air Conditioning
ICT	Information and Communications Technology
IoT	Internet of Things
PV	Photo Voltaic
SB	Smart Building
SBEMS	Smart Building Energy Management Systems
SH	Smart Home

Architecture and Building Technologies

AEC	Architecture, Engineering and Construction
AI	Artificial Intelligent
ANP	Analytical Network Process
BIM	Building Information Modeling
LEED	Leadership in Energy and Environmental Design
ML	Machine Learning
SDN	Software-Defined Networking

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CHAPTER 1

INTRODUCTION

The historical record demonstrates that humanity has continuously changed and developed. Furthermore, these are obligatory after a link in the chain. The interdependence of humanitarian requirements has significantly impacted human life, both positively and negatively. Despite the initial promise of enhanced convenience, the world has had to contend with the consequences of this relationship. The Industrial Revolution, which occurred over the past two centuries, is a pivotal example of this phenomenon. Following the Industrial Revolution, the demand for inexpensive labor in urban areas increased, prompting the relocation of individuals from rural communities. This shift led to a surge in urban population growth and a rise in the demand for affordable and rapid real estate. The last statistics demonstrate that more than 50% of the world population lives in cities [1]. Similarly, humanity is confronted with a multitude of challenges and potential solutions. Another significant issue is global warming, a consequence of climate change. This phenomenon has emerged as a prominent challenge, with glacial melting representing a key indicator of its impact. This resulted in adverse effects on agricultural land area and efficiencies, creating food supply chain issues. The other consequences of these developments are the contamination of the air, water and soil [2,3].

Over the past five decades, a further pivotal issue, termed 'energy', originated from the Industrial Revolution. Following this date, there was a notable increase in machinery fabrication, which led to the emergence of fuel as a means of providing the energy required for the devices to function. Energy, as the above-mentioned developments were taking place, its definition has similarly evolved, and each stage demands more energy. This is because the construction sector greatly impacts energy consumption globally, close to 30% of the total global energy consumption. It is also important to underline that more than 50% of electricity consumption worldwide belongs to the construction industry [4]. The detailed statistics demonstrate that energy

consumption is distributed across a range of activities, including heating, cooling, interior ventilation, water production, lighting, appliances, electrical equipment, transportation, and the use of cooling gases (21%), electricity (30%) and biomass (29%) [5]. Regarding carbon emissions, the construction sector is responsible for approximately one-third of global emissions. These emissions have increased water consumption, with the construction sector accounting for 25% of global water usage [6]. Construction-related energy and carbon footprint are the main public concerns now because the consumption of water, electricity, and all discrete forms of energy, as well as carbon emissions, is huge on a global scale due to the scale of the construction industry.

Each invention has resulted in the emergence of a new necessity and influenced the trajectory of human advancement. The most pivotal of these have endured as foundational elements in the present era, with the sourcing of raw materials during the Industrial Revolution representing one of the most pivotal. Furthermore, energy has also become a significant raw material. The acquisition and administration of energy have constituted a pivotal objective. The inception of this objective gave rise to more profound concepts and movements. The concepts of sustainability and renewability have emerged as key areas of discussion [7]. The term "sustainability" was fully defined and utilized at a conference, yet it is ultimately a well-established concept with established principles that apply to humanity. The maintenance of existing systems is of paramount importance in the current era. All devices and systems require inputs and outputs; however, limitations must be considered. These pessimistic forecasts prompted the development of strategies for monitoring and controlling potential risks. Due to these concerns, particularly those pertaining to digitalization, unmanned systems have been employed in many domains. This phenomenon is also evident in the construction sector. The fragmented nature of the construction industry, the sequential nature of the works that need to be carried out in an interconnected chain system, and the number of stakeholders with different interests involved in each project are cited as one of the main causes of problems in the industry [8]. A further issue is handling sensor data obtained from automatic sensors, which can be processed by applying specific calculations or using dedicated devices. Many processes within

the building are transferred to the system with the assistance of sensor data. The decision-making process depends on the system's authority, whereby either an automatic or semi-automatic mechanism is employed. The edifices for implementing this technology are also designated as "smart buildings." In other words, smart buildings can be defined as an integrated version of technology in buildings. Although smart building systems bring several benefits, specific issues have arisen concerning their operational efficacy and data storage [9].

People have become more aware of what data and data storage should be in the past few years. Traditional cloud systems are of no more use in the storage capacity or data integrity aspects, as they have compromised security and centralized control. Furthermore, it has been demonstrated that the manual coordination of the aforementioned processes, including contract management, transport requests and supply chain management, is laborious and inefficient when undertaken in complex construction projects and the associated paperwork. Conversely, blockchain technology has made it out during this time and provides new innovations regarding data integrity, decentralized control, and transparency. Researchers in the 1990s created the first theoretical concepts and definitions of BCT. Regardless, Satoshi Nakamoto has already given an exact definition in 2008 [10].

It is now widely accepted across all sectors that architecture is not merely a field concerned with creating physical designs using 2D or 3D software. Instead, it is also a field in which the constructed structure should function as an integrated entity with all surrounding areas, acting as a conduit for them. At the same time, it is clear from the construction sector context that this process is an extremely complicated multi-stage phenomenon, starting from negotiations between an architect and a client which end with a project transfer to production. These include monitoring construction, which would require checking in on how the building is coming along and visiting the site. Organizing these activities in an orderly and coordinated way is critically valuable. In the face of this new reality, the methods used are also being revised. In light of this consensus, incorporating novel technological advancements into the architectural domain is an unavoidable prospect. [11] posits that a fundamental prerequisite for

implementing blockchain technology in the architectural field is the extensive digitization of information, digital processes and a dependable digital infrastructure. So, as the AEC industry continues its inevitable digital transformation, the architects will find blockchain at their heart.

In the construction industry, in particular, technology is a major force propelling growth in consumption. To promote sustainability, it is critical for humankind to take steps toward controlling consumption. The above reasons are according to the principles of blockchain technology and the existing reasons for smart buildings. The keywords in question were mutually reinforcing, constituting a comprehensive and coherent set of arguments. With the changing technological landscape, architects must adapt and edge into Innovation to stay relevant. To discuss the usability of blockchain technology in terms of data processing and security for smart buildings, this thesis performs a literature review on the topic "blockchain technology" and "smart building". This thesis investigates the potential of blockchain technology to enhance the efficiency of smart building operations. Additionally, it assesses the prospective contributions of BCT to SB and explores the feasibility of integrating BCT into the energy system.

1.1 Definition of the Problems

When investigating smart building gaps literature, first three issues are data integrity, security breaches and centralized control keywords. The sensors would take the data in the smart building, they have to collect a store the traditional smart building system these can be a central server meaning a computer. This type of data storage and management is mostly treated malicious attack or get difficult of the remote control. As well, all steps can control just their selves. According to this problem, [12] discusses the potential of a decentralized authorization system to address the limitations of traditional, centrally managed building systems. Through blockchain for supporting smart contract, our system provides a scalable, tamper proof way to delegate access control between different administrative domains. This approach can provide dramatic improvement on the efficiency and flexibility of building

management systems, allowing for more widespread collaboration and public involvement with built environment management. On another major issue, [13] the proposed Trust-based Security System (TSS) effectively addresses the challenges of data authenticity, integrity, and secure transmission for resource-constrained devices in smart cities. The system utilizes a trust model and a robust routing algorithm to balance safety, transmission efficiency, and energy consumption, ensuring reliable data collection and minimizing potential security risks. [14] analyzed trustiness of the context-based evaluation system- Smart Building (CTES-SB) and also it compares with another algorithms. In conclusion, CTES-SB present verify in malicious environment. Smart building security research is growing in complexity, but lacks empirical evaluations and considers non-technical aspects like social, organizational, and human factors [15]. Smart Homes face security challenges due to low sensor capacity, multiple connectivity, and heterogeneous home systems, but future solutions should address these issues [16]. The last issue in the smart buildings centralized control or data silos. About this problem, [17] analysed real building data over a four-year period (2019-2022), a period that coincided with the global pandemic caused by the COV19 virus. This resulted in challenges to data quality and availability. The research involved the management of real-time databases for monitored buildings, particularly in terms of scalability and fault tolerance. The findings have the potential to inform more intelligent building control and energy management practices. [18] smart building energy management systems (SBEMS) have evolved to enable occupants to monitor, schedule, and modify building energy consumption profiles, while improving privacy, security, and interoperability (Figure 1.1).

According to these outputs, the vulnerable or misused issues are also investigated in a centralized system of smart building. The first thing coming mind is cloud based systems. [19] mention about that the cloud-based local energy management systems can reduce energy costs and improve security, but addressing security and privacy concerns is crucial for integrating electric vehicles and energy storage units. The other is about the data-driven learning-based algorithm for detecting unobservable false data injection attacks in smart grids, utilizing both autoencoders and a generative adversarial network framework. By leveraging the strengths of these models, the

algorithm enhances the detection of stealthy cyber-attacks that could otherwise bypass traditional security measures, ensuring grid resilience [20]. The adaptive neuro fuzzy inference system effectively mitigates the impact of false data injection in smart multi-area microgrids, reducing the impact of attackers and reducing the impact on operation costs by 8.52% [21]. These traditional systems are susceptible to significant threats from malicious users or hackers, particularly in relation to the privacy of user data. Camera, voice recognition systems, heating and cooling systems, water and sewage services, and biometric password systems are sensor-based devices that are especially exposed to cyber-attacks if they are connected to a cloud platform. Most probably, such systems are targeted by cyber-criminals since they handle sensitive information.

As the number of smart buildings continues to grow, so too does the severity and complexity of the security threats they face. Larger infrastructures, such as industrial buildings, hotels, and other commercial properties, manage a more extensive array of data, much of which is critical due to the nature of customer interactions and operational requirements. Although the data collected in individual smart building can be appeared to be of limited consequence, the data in larger buildings is of greater value, potentially exposing personal, financial, and operational details. This underscores the importance of protecting such systems. As smart buildings continue to expand in scale and complexity, ensuring the security of their digital infrastructure becomes increasingly vital to safeguarding user privacy and business integrity.

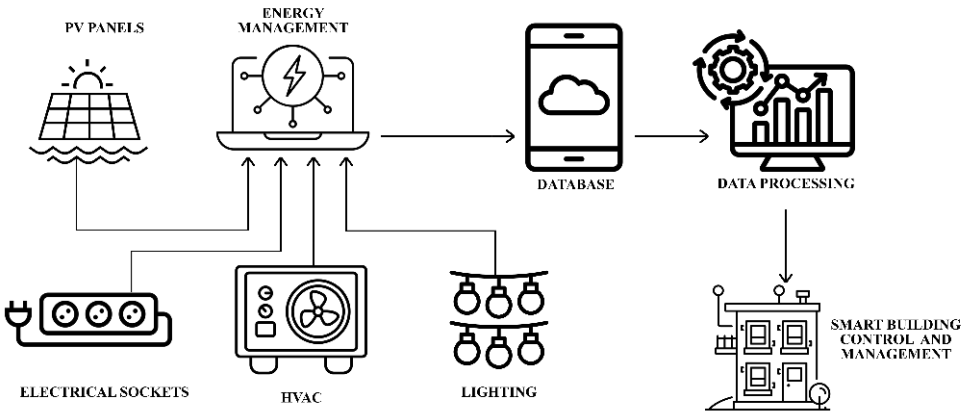


Figure 1.1 Using Cloud Base Systems in Smart Building Energy Management Process (Adapted by Author)

1.2 Aim of the Research

This research aims to examine the systems and technologies that underpin smart buildings, intending to identify the challenges, opportunities and prospective future potential of these systems. Decentralized blockchain technology, a form of data management technology, continues evolving and gaining traction across several industries. In the last years, academic studies on blockchain have been reproduced, particularly since 2008, which have importantly contributed to the existing body of literature on this topic [22].

Globally, there is a growing interest in the potential of blockchain technology and smart buildings to provide more efficient, secure, and scalable solutions [23]. This growing interest is evident across multiple sectors, particularly among researchers, industry leaders, and governmental bodies, all of which recognize blockchain's vast potential for smart building systems [24]. Türkiye is also following this global trend, with notable advances in the adoption of blockchain technology across various fields (Figure 1.2). Nevertheless, despite the growing number of studies, original research on integrating blockchain technology within smart buildings remains scarce.

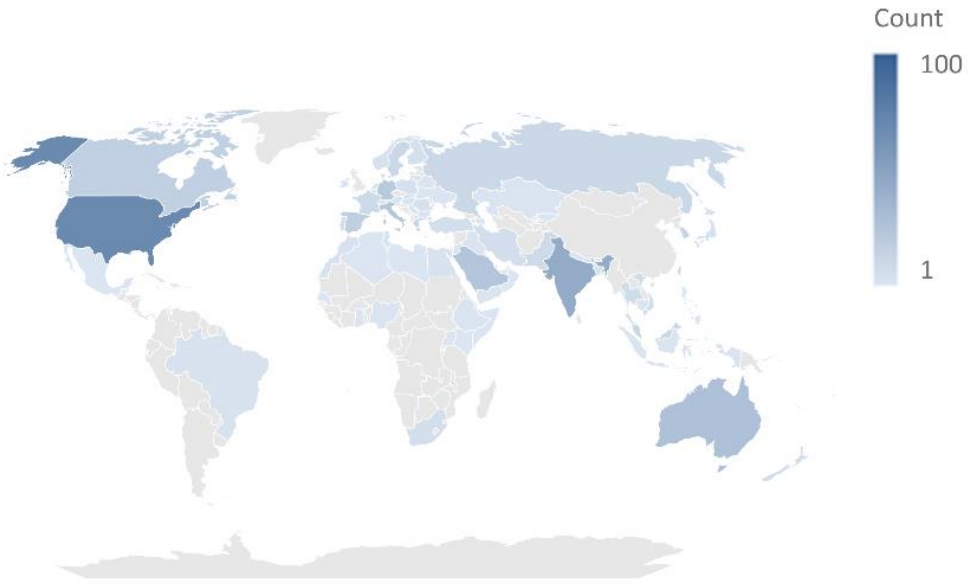


Figure 1.2 Global Distribution of Count-Based Academic Research by Country (source: Web of Science)

In light of this gap, this research aims to provide a comprehensive evaluation of the intersection between blockchain technology and smart buildings, focusing on Türkiye and its architectural sector. This thesis will contribute to the emerging discourse in both academic and practical contexts by addressing these critical areas. The following research questions will be examined:

1. How can blockchain technology address smart building infrastructures' identification, authentication, and authorization challenges?
2. What are the most common problems related to data management and security in current smart building infrastructures?
3. How do smart buildings' traditional identification, authentication, and authorization mechanisms fail to provide sufficient security and privacy?
4. How can a blockchain-based infrastructure improve security, data integrity, and user access control in smart buildings?
5. What are blockchain technology's key challenges and limitations in smart building environments?
6. What role can decentralized identity management systems play in improving identification and authorization processes in smart buildings?
7. In terms of sustainability, what are its contributions to the construction industry, where blockchain technology is integrated?
    a. What are their contributions to the construction sector?
    b. How will these systems sustain their selves?
8. Can the data transfer system powered by blockchain technology be used to maximize the efficiency of smart grids?
9. Is it feasible and efficient to implement Blockchain technology in smart buildings, and what model, stakeholders, and standards are crucial for success?
10. Which large-scale projects (e.g., hotels, malls, airports) are most suitable for smart building technologies?

1.3 Research Method

A comprehensive literature review was undertaken in the thesis study's initial phase. In this phase of the literature research, a comprehensive account was provided of the fundamental concepts associated with smart buildings and blockchain technology. This included an in-depth examination of the historical development, operational principles, and the various categories in this field. The subsequent phase of the study entailed an examination of the research literature about the potential applications of both keywords, individually and in combination, with a particular focus on temporal, geographical, and sectoral aspects. The steps of this analysis are illustrated in Table 2.2, Table 3.1, Table 4.2. In the initial phase of the literature search, a range of articles, reports, conference papers and theses were identified through the use of the keywords “Blockchain technology, Smart Building, Energy Management” across the databases Web of Science, Scopus, EBSCOhost, ASCE, Emerald, Google Scholar, Science Direct, Taylor & Francis. The rationale for selecting these research databases is based on the quality of their publications, which provide comprehensive coverage of high-impact, multidisciplinary research and studies conducted globally. Subsequently, publications not pertinent to the construction sector, particularly those related to architecture, were excluded. The publications were evaluated according to several criteria, including keywords, country of origin (Figure 12), year of publication (Figure 1.3), type of publication, publishers and journals. to ensure adequate article coverage. Articles published between 2007 and 2024 were analysed to understand the innovative features and importance of the project comprehensively.

The Figure 1.3 illustrates the number of academic publications on blockchain technology in smart buildings (depicted in blue) and the number of citations to these publications (depicted in black) by year. The graph illustrates a notable surge in interest in this field between 2016 and 2024. From 2018 onwards, there has been a gradual increase in the number of publications, which has risen in parallel with the number of citations, reaching a peak in 2022 (Figure 1.3). As of 2023, there has been a slight decline in the number of citations, yet the number of publications continues to

grow. This illustrates that blockchain technology in smart buildings is garnering increasing attention and discourse within the academic community.

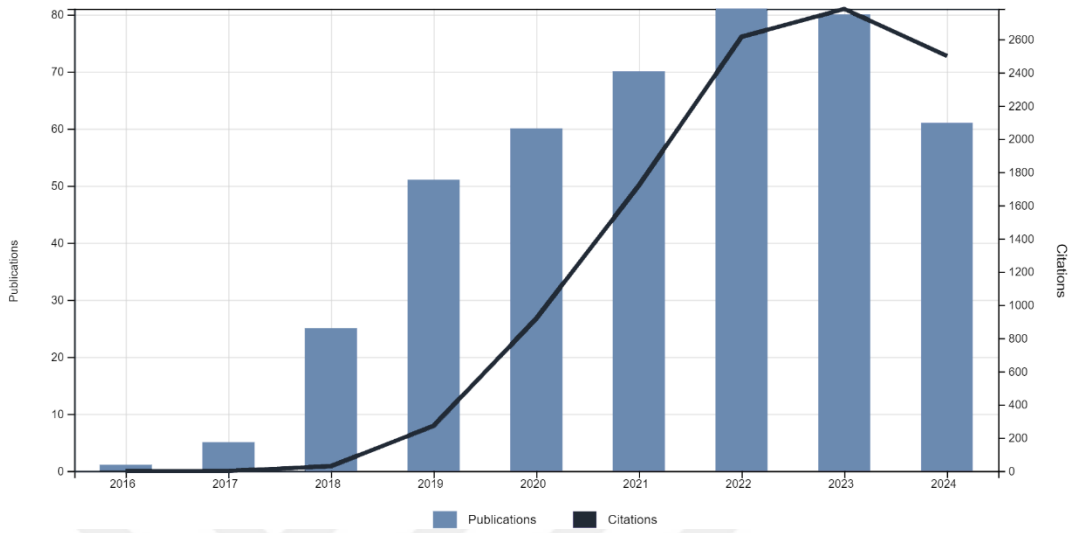


Figure 1.3 Publication and Citation Ratio by Years (Source: Web of Science)

The methodology section is organized as follows: Chapter 2 discusses literature related to Smart Buildings, Chapter 3 provides a literature review of Blockchain Technology and Chapter 4 presents collaborative work on Blockchain Technology and Smart Buildings. Subsequently, a research roadmap was devised and analogous and subsequent studies were identified. In order to evaluate the inferences made from the literature, an analysis was conducted of the Internal Combustion Engines Department Laboratory Building at Széchenyi István University in Gyor, Hungary, with a particular focus on the management of energy resources. After that, the applications of blockchain technology in smart buildings were determined and the advantages it can offer were evaluated using the ANP method. Finally, the potential benefits of smart building systems with the integration of blockchain technology were discussed, considering the growing significance of energy management in recent years and the various dimensions of buildings.

The following flowchart (Figure 1.4) provides a summary of the steps involved in the literature review on the integration of blockchain technology into smart building systems. The research is organized into three main sections: smart buildings,

blockchain technology, and the integration of the two. The studies were evaluated according to a set of criteria, including geographical location, sectoral focus, publication year, and type of academic source. A range of databases were consulted in the process, including Web of Science, Scopus etc. The results were subjected to analysis using the Analytic Network Process (ANP) method, with a view to identifying potential areas of use, advantages and disadvantages.

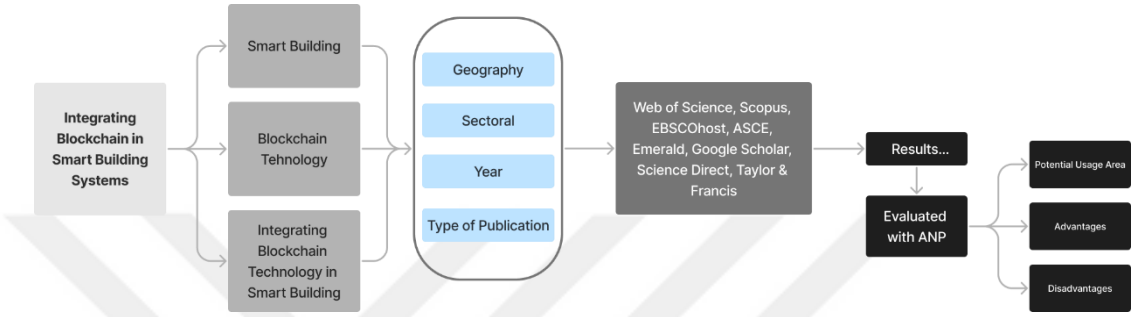


Figure 1.4 Research method steps (Created by Author)

1.4 Overview of Blockchain Technology and Smart Building

When analyzing literature on the use of Blockchain Technology in Smart Buildings, studies are reviewed based on three main subheadings: smart buildings, blockchain technology, and joint studies involving both keywords. Most studies under the subheading of smart buildings focus on energy management. Within the examined studies, several methods have been proposed for data and energy control in smart buildings. The focus of the methods employed primarily centers on cloud systems. The most frequent subheadings in the literature are data integrity, security breaches, and centralized control. In contrast, BCT offers data integration, honest and secure network access, and a decentralized system. This part, which was analyzed under the key category of Blockchain Technology and Smart building systems and collaborative studies (Figure 1.5).

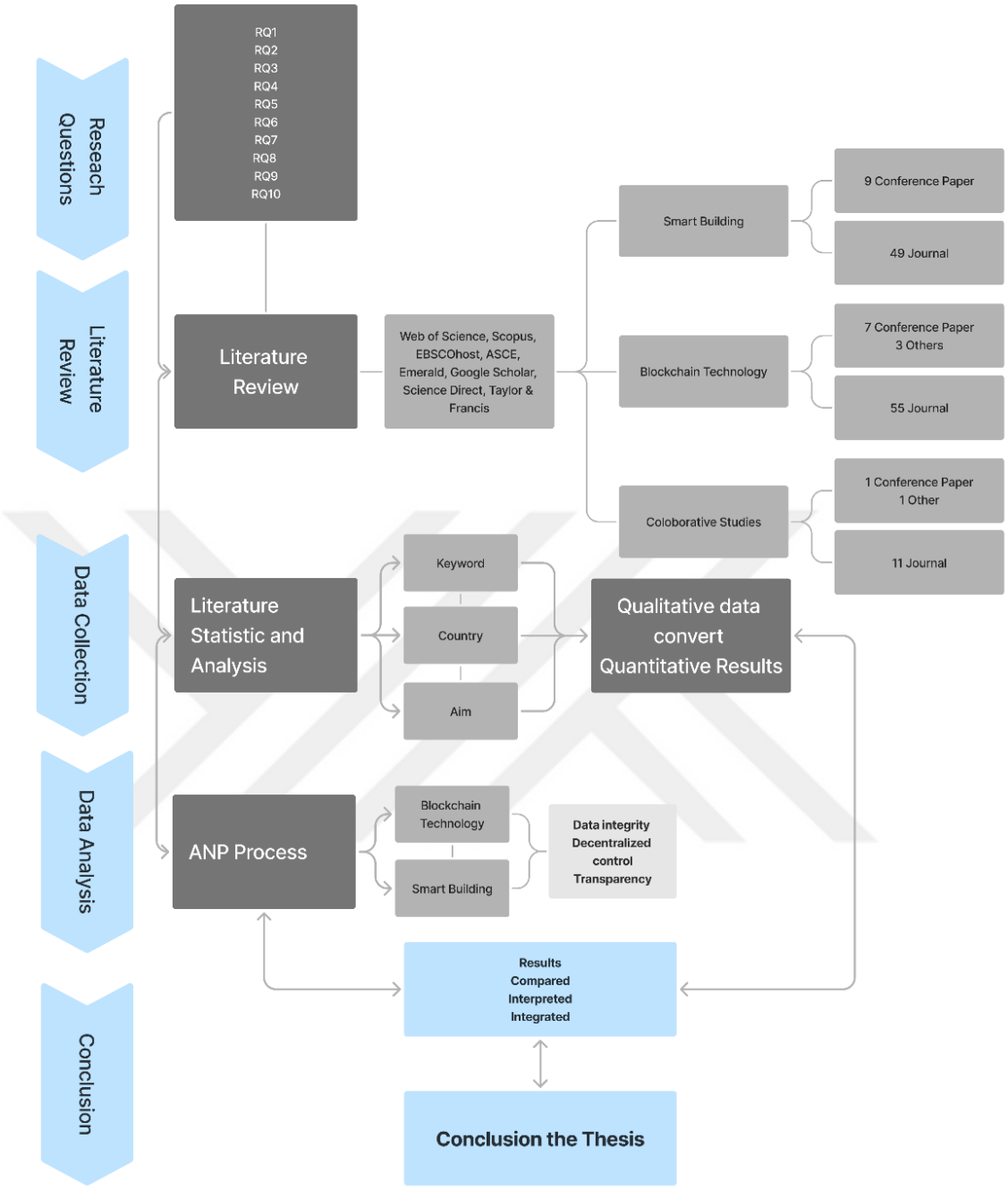


Figure 1.5 Study steps Literature review (Created by Author)

CHAPTER 2

SMART BUILDING

Smart buildings are systems in which the building's energy use is automatically controlled by the building's own elements and additional equipment to increase energy efficiency. Therefore, the most important task of a smart building is to minimize the energy consumption of the building without compromising the comfort of the users. In Türkiye, as in the whole world, a very significant portion of the total energy is used for heating, air conditioning, ventilation, lighting, etc. to provide user comfort in buildings [25]. In order to understand what the proponents of the smart building concept are trying to achieve by implementing this concept, asking the question "What is a smart building?" instead of "Why smart buildings?" offers us a much more profitable line of development [26]. In essence, smart buildings are the buildings of the information age. But how does this change manifest itself in smart buildings? What are the criteria for calling a building smart? What is being done at the academic and sectoral levels? Section 2 attempts to answer these questions.

2.1 Smart Building Criteria and Definition

With the rapid development of technology, the concept of "smart building" has become increasingly important in building design and construction processes. Smart buildings go beyond the classical building concept by combining different technological solutions to optimize elements such as energy efficiency, security, user comfort and sustainability. In this context, the attributes and performance criteria of smart buildings aim to better respond to changing user needs and environmental requirements by pushing the boundaries of building technologies. Under this heading, the basic criteria of smart buildings and the features that distinguish them from traditional buildings are detailed.

2.1.1 Smart Building Background

Smart cities evolved from intelligent buildings, green resilient buildings, and green construction, incorporating features like energy savings, sustainability, and building resilience with the rapid advancement of ICT. The concept of smart city emerged in the 1980s, following the exploration of alternative energy sources and energy-saving measures in the 1970s and 1980s [27]. One of the earliest examples of a smart building is the City Place Building in Hartford, Connecticut, completed in 1983. This 38-story building was an early adopter of centralized control to monitor and manage energy consumption, a precursor to today's Building Management System (BMS) to optimize performance. Pharos Control transformed how buildings are designed, built, and operated, proving the value of tech-enabled efficiency in the built environment as an open platform that quickly captured the imagination of a powerful segment of commercial property [28].

By the 1990s, the rapid advancement of the Internet and sensor technologies led to a new wave of smart building developments—the incorporation of Internet of Things (IoT) devices into buildings enabled real-time monitoring and data collection. A study conducted by [29] IoT-based systems in commercial buildings can lower energy consumption by about 30.86% using the Constrained Application Protocol (CoAP). This data highlights the impact of connectivity and data analytics in improving the operational efficiency of modern buildings.

Since the early 21st century, the focus of smart building technologies has shifted towards sustainability and occupant well-being. The International Energy Agency (IEA) estimates that buildings represent over around 40% of global energy consumption, and interest in intelligent technologies is critical in reducing this figure [30]. With the increase through criteria associated with green building certifications, for example, in LEED (Leadership in Energy and Environmental Design), smart buildings are now being designed with sustainability at their core. Smart technologies help manage renewable energy sources, optimize lighting, and control water usage, significantly reducing a building's environmental impact.

Nowadays, blockchain technology is becoming a game-changing effect on smart buildings, helping to improve security and energy management. BC can enable transactions to be controlled by a decentralized population and create greater transparency in the use and storage of energy. Studies have shown that integrating blockchain into smart grid systems can reduce energy losses by up to 30% and improve the security of energy transactions (Van Leeuwen et al., 2020).

The journey of smart buildings is ongoing and continues to be shaped by advances in artificial intelligence (AI), big data and smart materials. The global smart building market would grow from $80.62 billion in 2020 to $121.6 billion by 2026; this growth is a result of increasing demand for energy efficiency, security and better resource management [31].

In conclusion, the history and development of smart buildings have been marked by continuous technological progress, with a crucial focus on energy efficiency and sustainability. From the early integration of building management systems to the use of IoT, AI, and blockchain, smart buildings will continue to evolve to meet the needs of the modern world.

2.1.2 Smart Building Definition and Criteria

Smart buildings can be expressed as automatically controllable buildings distantly. Devices or appliances need a connection network that can be managed via mobile phone or monitoring vehicle. Internet technology is the most important invention for this. All home vehicles can be added control plugs and connected with a smartphone. Distances are not crucial for most duties; users can open or close electrical vehicles, control times or issues, and command working time. Control capacities include security access, lighting, temperature, vehicle control, and home theater [32].

The concept of a smart building is not merely the utilization of advanced or intelligent systems; it is a more expansive concept. It comprises a comprehensive framework that integrates various technologies and practices to create an intelligent, responsive, and efficient environment for its occupants. As defined by [33], a smart building is a

building with changeable characteristics that can respond with minimal human interference to changes in the external and internal environments. In doing so, it prioritizes occupant comfort while considering financial benefits and energy reduction. This illustrates the building's capacity for dynamic adaptation to varying conditions, with a particular focus on automation and optimization.

Similarly, another definition places emphasis on the necessity for a smart building to "integrate automated building controls and optimize operations in order to reduce both costs and energy usage in comparison to conventional buildings." This reflects the economic and environmental imperatives of smart buildings, which focus on efficiency, cost-effectiveness, and sustainability.

“Smart homes are, in their simplest definition, the computerization of housing. They gather data on inhabitants and their habits with a range of sensors; by analyzing these collected data, they respond to these actions and events by controlling certain mechanisms built into the housing.” [34]

A review of the literature reveals that there is no consensus on the dimensions and indicators of a smart building.

a) Based on Literature Results: The existing literature offers a range of proposed dimensions and indicators for measuring smart buildings. While [33] discuss indicators energy management, health and safety, automation, occupancy control, communication and data sharing, sustainability features are accepted smart criteria according to literature results. All these headings have subheadings (Figure 2.1).

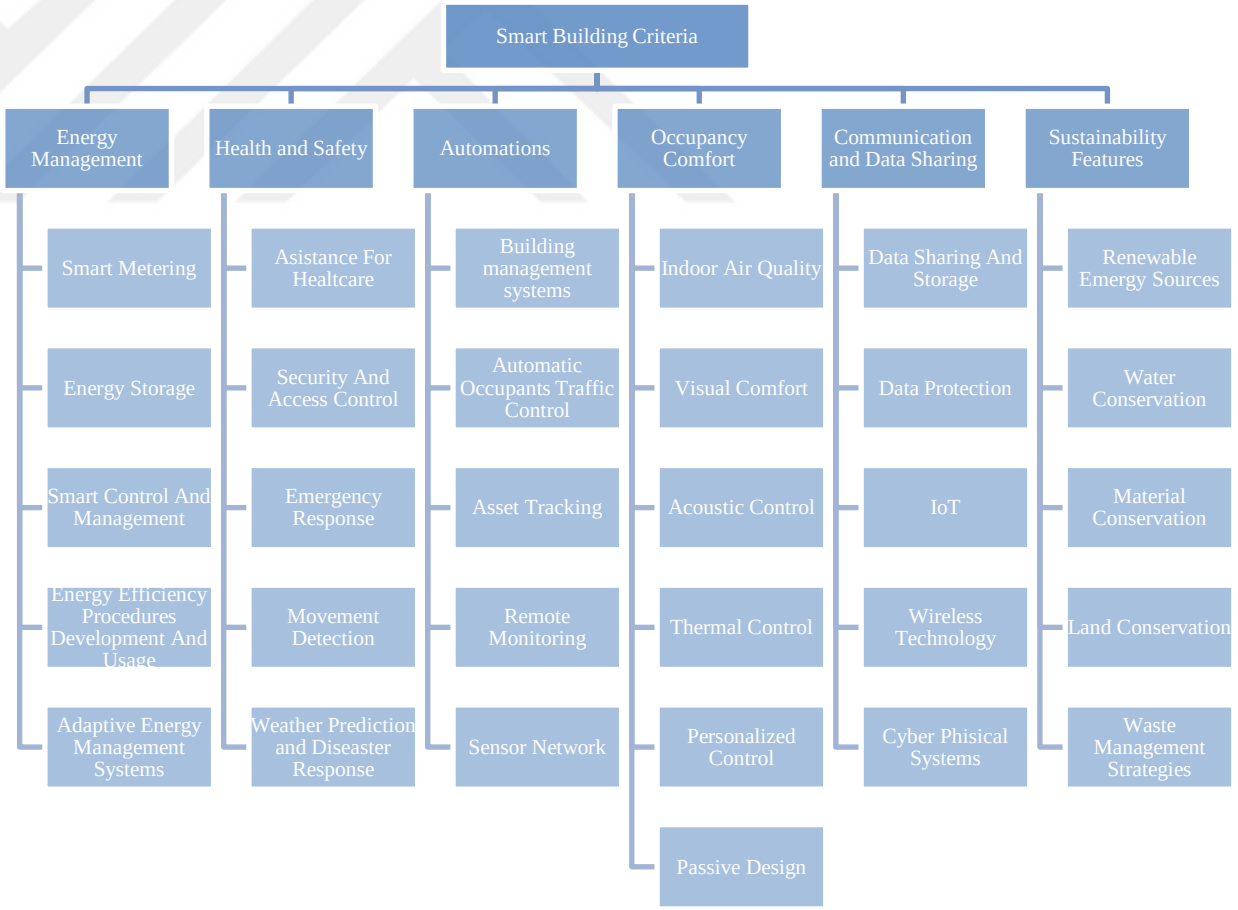


Figure 2.1 Smart Building Criteria (Adapted by [35])

b) Based on smart criteria certifications: As a consequence of comprehensive research, sophisticated criteria and certification systems have commenced development for smart buildings, in a manner analogous to that observed in the context of green buildings. The most frequently selected keywords are access, energy, security, health, sustainability, automation and data management (Table 2.1). These headings are also at the forefront of the criteria examined, which employ different measuring systems. A number of certification systems have been developed with the objective of measuring and certifying the various smart characteristics of buildings. Such systems include Spire, Smartscore & Wiredscore, Boma Best Smart, Smart Readiness Indicator, Intelligent Building Index and User Oriented Smart Building. The parameters considered by these systems include access, energy efficiency, connectivity, cyber security and property security, health, sustainability and operation, community and service, automation and control, data management, resilience and user experience. To illustrate, the Spire and Smartscore & Wiredscore certifications encompass a comprehensive array of parameters, whereas the Boma Best Smart and Smart Readiness Indicator certifications are more concentrated on energy, automation and data management. In the context of the growing expectation that buildings will be smart, the certifications recognize that the digital infrastructure of properties, as well as their performance in relation to sustainability, represent a key focus. The following table provides a comprehensive overview of the scope and focus of various certification systems, offering a valuable reference point for understanding the priorities and parameters that define a smart building system.

Table 2.1 Parameters of Smart Building Certifications

	Access	Energy	Connectivity	Cybersecurity& Property Safety	Health	Sustainability & Operation	Community & Service	Automation & Control	Data Management	Resilience	User Experience
Spire	X	X	X	X	X	X				X	
Smartscore& Wiredscore	X	X	X	X		X	X	X	X		X
Boma Best Smart		X	X	X				X			
Smart Readiness		X			X	X		X	X		
Intelligent Building	X	X	X	X		X		X			
User Oriented Smart	X					X			X		X

1

A smart building is an adaptable and efficient structure incorporating advanced technologies to increase comfort, reduce energy use, and optimize costs. These self-sufficient systems must take into account several criteria in order to ensure optimal functionality. Energy and network connectivity are among the fundamental characteristics of smart buildings. While network connectivity facilitates internal and external communication, it is imperative to recognize that these systems cannot operate without energy. The primary objective is to guarantee that the disparate components of the edifice, including illumination, heating, cooling, security and automation systems, operate in a unified and intelligent manner. Nevertheless, a multitude of variables must be taken into account when assessing the efficacy of a smart building. Energy efficiency represents a fundamental indicator of the sustainability of a building. It constitutes a significant stride towards curbing energy consumption by implementing streamlined systems, including automatic lighting, heating and cooling, and integrating renewable energy sources. Automation and control systems represent the fundamental building blocks of smart buildings. The extent to which building systems are automated and can operate with minimal human intervention is a critical measure of a smart building. Moreover, the connections must function effectively and securely, with no vulnerabilities in the data transfer process. In terms of security, it is necessary to consider data security and the security of the property in which the data is stored. The reliable and secure functioning of sophisticated security systems, such as alarm systems and biometric access, is paramount to the user. It is incumbent upon smart buildings to enhance the comfort of their residents by maintaining optimal conditions for air quality, temperature, lighting, and acoustics. It is imperative that smart building systems, which have commenced integration into sustainable edifices, also prioritize waste management, water conservation, and carbon emission monitoring applications. Furthermore, in addition to these, the monitored components should provide financial benefits by reducing operational and maintenance costs through automatic systems due to integrating systems throughout the entire building. Regardless of the scale of the building, it can adapt to changing needs thanks to every scalable technology, which also offers a user-centered experience.

2.2 Smart Building Literature Review

The detailed literature review on the keyword "smart buildings" provides a comprehensive analysis of academic studies in this field. This section presents a variety of statistical data regarding the types of publications, distribution by year, subtopics covered, and general objectives of the studies. The data obtained provides insight into the evolution of academic interest in smart buildings over time, the prominence of specific sub-topics, and the primary objectives of research in this field, including energy management, security, and data integrity. These statistics provide a valuable point of reference for gauging the current state of smart building technologies and identifying future research needs.

The literature review has identified six key Smart Building topics. The literature analysis on the keyword Smart Building reveals 58 studies conducted between 2010-2024 (Appendix A). The studies focus on energy management, remote control, and IoT subheadings. It is noteworthy to mention the countries where the studies were conducted, with the top three being the USA, India, and Türkiye in the literature review. Upon examination of the literature, the majority of research articles found are review articles published in academic journals. This section presents a comprehensive literature review addressing the questions posed. While prior research has investigated smart building technology, this study distinguishes itself by critically evaluating the feasibility of integrating SB technology with blockchain technology from an architectural viewpoint. [36] are among the researchers who have examined the complexity of terminologies and the objectives defining the smart building terminologies utilized in the industry.

The majority of studies have focused on energy management (Appendix A). [37] discuss the HVAC system and its requirement for dynamic control. According to their paper, unifying inputs to the HVAC controller is crucial for improving energy efficiency. Furthermore, the article details developing and implementing an affordable, easily distributed occupancy detection system utilizing battery power. [38] examining the performance of various energy storage vehicles in a microgrid was undertaken. These were subsequently compared. [39] aim to calculate energy

consumption in smart homes using mixed integrated linear programming (MILP). This program was designed to operate the energy consumption in the smart building, and at the same time, it provides real-time electricity pricing. [40] this study aims to analyze the latencies between smart home devices via the ZigBee protocol. Smart home appliances such as fridges, dishwashers, air conditioning units, washing machines, water heaters, ovens, and televisions are integrated with smart plugs. ZigBee, a communication technology between devices, is utilized in this study to manage WPAN and the communication nodes of device-to-device networks. In conclusion, ZigBee provides sufficient communication performance. [41] analyzed Smart Building Energy Management Systems (SBEMS) and Conventional Building Energy Management Systems (CBEMS) concerning energy consumption and management. The results indicated that SBEMS led to a reduction in waste energy consumption. [42] proposed an agent-based approach to optimize the inter-operation of smart grid and building energy management systems, comparing them with multiple numeric examples. [43] presented the advantages and disadvantages of using AC and DC distribution systems for energy efficiency in smart houses. [44] aim to develop a new framework for managing energy in commercial buildings with a two-level grid. The study presents a bidirectional building-to-grid optimization approach based on experimental data. [45] describe a platform-based methodology for designing smart buildings and explain the various design components. [46] aim to develop a new deep learning algorithm for controlling energy consumption in smart buildings, and the paper presents a comparative analysis of predictive models. [47] demonstrate that a transfer learning system can be used to develop an intelligent human counting system. Thus, energy management over other methods. In their study, [48] discuss the potential risks of cyberattacks in SH energy management and the formulation of energy consumption using devices in smart homes. [49] identified three types of smart home technology applications, namely, energy management, including monitoring energy consumption and efficiency; utilizing AI technology and ML algorithms; and implementing aged-care and wearable health monitoring systems. In a study, [50] compared machine-learning-based solutions for occupant-centric and device-centric/energy-centric approaches. Previous research has mainly concentrated on energy efficiency and recommended real-time monitoring and actuation. However, this paper proposes using

machine learning to predict user behavior. [51] aimed to provide a comprehensive literature review on energy management in smart buildings. The review objectively examines existing structures and systems while emphasizing the flow of information and causal connections between statements. BIM is employed for energy management, heating, ventilation and air conditioning operations, monitoring, and planning. [52] discuss challenges in smart building energy management and efficiency and provide a comprehensive literature review for smart building energy management and deep reinforcement learning keywords. [53] focused on predicting energy consumption using machine learning systems, working in a case study area in Malaysia. [54]introduced a novel model for an energy management system which utilises Supervisory Control and Data Acquisition (SCADA) technology. [55] discuss multidimensional approaches to energy conservation, utilizing artificial intelligence to manage city infrastructures through machine learning techniques in smart buildings. [56] explore the requirements of smart cities, their energy sustainability, efficiency, and how urban planning impacts them. In their review, [57] examine developments in 5G technology and the influence of smart home applications. The text provides a detailed analysis of the features and opportunities of smart cities and 5G use cases. The findings are based on a case study conducted in Singapore. The study suggests that advanced technology provides new opportunities, particularly in fields such as smart grids for cities, which are supported by 5G technology. Singapore serves as a prime example of this phenomenon. [34] highlights the effects of smart technologies on human life, including the potential for smart homes and the creation of smart cities. One significant benefit of these developments is improved energy efficiency.

The second most researched subheading in this paragraph is "remote control," listed chronologically. [58], which offers software solutions for energy management in buildings. [59] proposed an IoT-based approach for controlling smart buildings. The authors aim to improve the efficiency and effectiveness of building management through the use of advanced technology. The study focuses on indoor localization, sensor data, and monitoring through IoT applications. Technical terms and abbreviations are explained for clarity, and the text is written in a clear, concise, and logical structure. [60] proposed a novel management system called Brick for intelligent buildings. It offers a clear understanding of tags and tag sets for specifying sensors.

[61] introduce a novel technology called OCTOPUS, designed for enhancing energy efficiency in smart building energy consumption systems. [62] discussed the emerging implementation of features and controlling parameters in IoT infrastructure. This paper suggests significant changes for IoT-based control systems. [63] propose a real-time management system for smart buildings aimed at controlling various aspects such as indoor conditions, security, cost and comfort criteria, amongst others. [64] introduce a novel approach to gathering and contextualising essential post-occupancy data, comprising two distinct types. Additionally, the paper outlines innovative techniques applicable to BIM. The results of the study provide evidence of BIM's potential to function as a reliable single source of truth. Meanwhile, [65] analyse the effects of pandemic situations on building consumption habits and how building-related vehicles can benefit humans, shedding light on potential areas for future research. In their work, [9] discuss what the Internet of Things (IoT) is and why it should be adapted to the concept of smart homes. However, there exist pros and cons to this topic and technology. As such, this study aims to explore the technical, technological, psychological, and human perspectives associated with it. [18] systematically examined the literature on SBEMS and explored future studies and improvements for privacy and security. The paper provides detailed definitions of smart ventilation, heating, and air conditioning systems, lighting, plugs, windows, and energy optimization.

The third significant subheading focuses on IoT field studies within the smart building domain (Appendix A). These studies are listed below [66] aimed at developing novel, efficient smart home control systems accessible via smartphones. It also describes the system architecture of IoT fog and cloud-based systems. [67] provided definitions for IoT, WIFI, and ZigBee, as well as the potential for sensor technology to be used in apartment monitoring and control. Sensor technology can be divided into various categories such as leak detection, smoke alarms, fire alarms, water and electricity usage monitoring, lighting control and heating systems. [62] discussed the emergence of feature implementation, control parameter and IoT infrastructure in this field. The paper suggests important changes for IoT-based control systems, with a particular emphasis on the need for a clear and logical flow of information and causal connections between statements. [68] propose the use of blockchain technology or a

security and control framework to measure the effectiveness of these systems. This topic also explores the integration of IoT and BIM technologies. The reason for suggesting this system is due to the high number of stakeholders involved in the construction sector. A crucial aspect discussed in the paper is the adoption and integration of BIM and CIM. Their work also explores the design and application of an IoT-based cloud BEM system. [69] presents a comprehensive literature review on the optimization of energy consumption in smart homes. Technical abbreviations will be explained upon first usage. Quotes are clearly marked and filler words are avoided. The majority of researchers have prioritised indoor comfort in accordance with established standards. [70] propose a secure and transparent IoT control and management system for smart buildings. This is achieved through the use of software-defined networking (SDN) and blockchain technology. It described how blockchain technology provides transparent security. The proposed system is intended to ensure that the IoT devices are controllable, highly scalable, and secure. [49] have identified three types of smart home technology use: a) energy management in smart homes, including monitoring energy consumption and efficiency, b) applications of AI technology and machine learning algorithms, and c) aged-care systems and wearable health monitoring systems. In their manuscript, [57] review and discuss the impact of 5G technology developments on smart home applications. The text thoroughly analyses the features and opportunities of smart cities and the use cases of 5G technology. The results are based on a case study conducted in Singapore. It was found that advanced technology presents new opportunities, and 5G technology provides substantial support for various fields, particularly for smart grids in cities. Singapore serves as a significant example of this phenomenon. [9] present an exploration of the IoT and its adaptation to SH. While the advantages and disadvantages of this technology are recognized, the study aims to examine it from technical, technological, psychological, and human perspectives.

Sensor field studies figure prominently in the chronological sequence of related literature. [71] concentrated automation systems in smart buildings for energy management and recommended alternative systems. [72] investigated indoor environment quality and energy savings through various sensor data. This paper provides a foundation for future studies and addresses challenges and improvements

related to sensor types and fields of application. [65] examines the impact of pandemic situations on building consumption habits and the benefits of building-related vehicles for humans. They analyze these issues and establish a new area for future research. [73] introduce a novel software architecture for managing smart buildings that enables a digital twin. This provides users with sensor data, which can be monitored in the digital twin software.

The primary goal of this study is to analyze blockchain technology and its related fields, including the security and control frameworks (Appendix A). [68] proposed measures to evaluate blockchain technology. Additionally, this topic encompasses IoT and BIM technologies. The construction sector is highly complex and involves a large number of stakeholders, making the implementation of this system particularly relevant. Another vital aspect discussed in the paper is the integration of BIM and CIM. [70] define an Internet of Things (IoT) control and management system for smart buildings based on software-defined networking (SDN), supported by blockchain technology for security and transparency. [74] Investigate the integration of technology in smart buildings and cities, including the use of blockchain for various applications such as information exchange and energy trading.

The smart grid or smart city is also a related topic under this heading. [75] aim to explain the characteristics of the smart building and compare them with the smart city context. And study showed that smart cities provided smart building integration. The authors mention EU and SRI ratings and standards. [42] Proposed an approach with agent-based for the optimised operation of the smart grid/building energy management system and compared with some numerical examples. [76] Discussed today's application of the smart building and the status of IoT in the smart city context. This paper showed different perspectives of smart city applications and used "souly" program for monitoring or managing the building. [56] smart cities and their requirements, energy sustainability and efficiency and how urban planning affects them. [57] review and discuss in this manuscript that 5G technology developments and how smart home applications are affecting this. The text analyses in depth the features and opportunities of smart cities and 5G use cases. All of these findings are examined through a case study of Singapore. The following result was obtained that advanced

technology give new opportunities and 5G technology support to many fields and especially smart networks meaning cities. Singapore is the most important example for this. [34] express how smart technologies affect human life and potentials of smart homes and creating smart cities and one of the positive effects on energy efficiency. [74] investigate the integration of some technologies in smart buildings and smart cities and the use of blockchain technology, which gives some other options. For example, exchanging information, buying and selling energy.

A review of the literature reveals that the concept of smart buildings is most commonly associated with energy management. Energy management is a crucial aspect of optimizing resource utilization, reducing expenditure, and advancing sustainability. In this context, the Internet of Things (IoT) technologies and sensor data represent crucial instruments for the effective monitoring and control of energy flow in buildings. The deployment of Internet of Things (IoT) devices and sensors enables more efficient decision-making by management systems through the collection of energy usage data. Therefore, given the centrality of energy management, IoT and sensor technologies can be considered supporting elements of this system.

CHAPTER 3

BLOCKCHAIN TECHNOLOGY

Construction projects necessitate the participation of a multitude of stakeholders and organisations, which can give rise to conflicts among these actors due to the large-scale nature of such projects. Furthermore, the construction industry is confronted with considerable challenges, including low efficiency, inadequate regulation and compliance, limited cooperation and information sharing, and suboptimal payment methods [78]. As the sector expands, it becomes challenging to preserve trust among stakeholders. The intricate web of relationships hinders the free flow of information, leading to delays and elevated operational expenses [79]. The construction industry struggles with lack of trust, overdependence on intermediaries, and high costs, but despite these efforts, value creation is insufficient.

3.1 Blockchain Technology Background

The conceptual framework of blockchain technology was initially articulated by Haber and Stornetta in an article published in 1991. The researchers put forth a proposal to create a timestamp to enhance the security of digital documents. The timestamp, as mentioned earlier, would provide the user with the document's creation date information. Furthermore, the timestamp would provide an accurate record of the order in which the documents were created, thereby preventing any subsequent tampering [80]. In 1992, Haber and Stornetta further optimized the Merkle Tree Structure by incorporating it into the design. Consequently, the overall structure became more efficient, as storing multiple records in a single block was possible. In 2008, an unidentified individual or collective, operating under the pseudonym Satoshi Nakamoto, published a technical review in which a digital currency application called Bitcoin was developed using blockchain technology. [81]. Subsequently, the digital currency Bitcoin, which employs blockchain technology, emerged as a solution to the trust problem inherent to the currency system [82] The blockchain is the system that allows tracking of all assets and transactions in a business network. Another definition

is a decentralized distributed ledger technology that faultlessly creates, confirms and records encrypted processes of digital assets [83].

The system is working in this way (Figure 3.1);

- Each process saves as a data block
- Each data block has a connection with before and after
- Any operation cannot be undone, and it is saved into a chain in a blockchain, which is a chain [84].

In the traditional system, databases are used, and they work on a server, and other channels connect with the host server. However, blockchain technology (BCT) means decentralized systems. It can also be defined that this network occurs on many computers, although in a way that the data cannot be shifted without the unanimity of the whole network. Each block has a hash and connects with the previous block or hash [83]. So, blockchain has proof of work for recording all steps in detail.

When examining the chronology of blockchain, there are three plunge points [85].

1. Blockchain 1.0: Decentralization of money and payment
2. Blockchain 2.0: Decentralization of markets
3. Blockchain 3.0: Decentralization of government, science, health, art, culture. Meaning is that application beyond money and market

There are three main elements for working; block, chain and network. The block is where places of transactions are recorded. Chain is that connection of the creation blocks each other. Network namely the whole system [10].

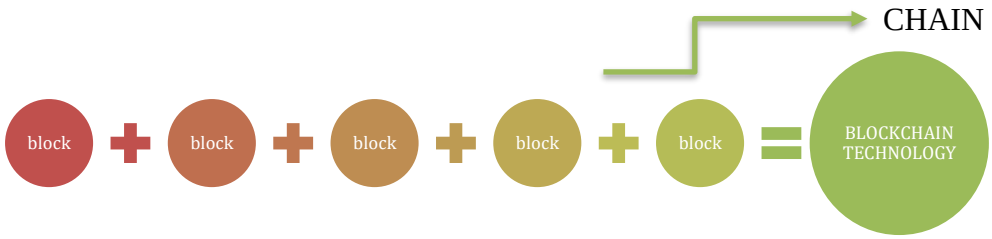


Figure 3.1 Blockchain main elements diagram (Created by Author)

Although blockchain technology (BCT) is a solution to many problems, its main subjects are scalability, reliability, and decentralization. These three issues should work together to create a good system.

A survey has done which conducted asking about the main supporting elements of blockchain technology (BTC) that is being used by businesses in which more than 50 companies participated (Figure 3.2). The survey participants answered that 61.5% of the respondents said transparency, 58.5% immutability, 40.8% trust, 33.7% of them answered decentralized, and 20.1% of them as cost reduction, intermediation, and automation, which are described as other [86].

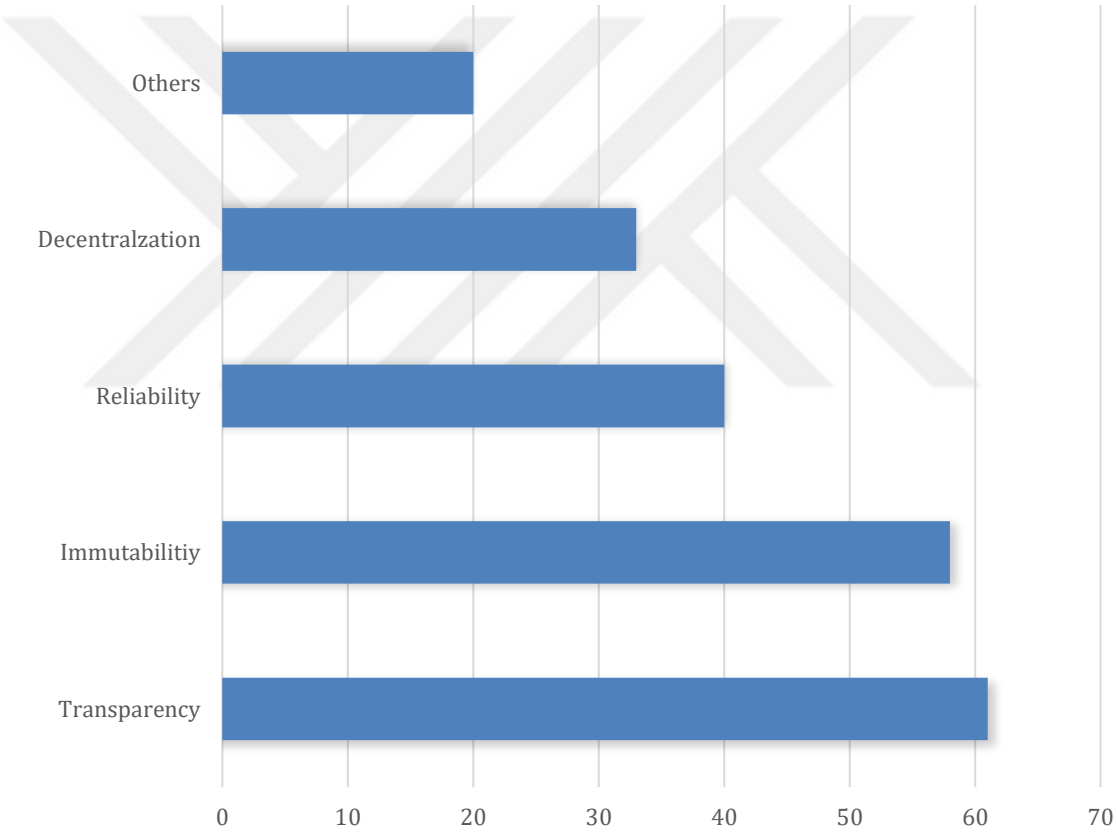


Figure 3.2 Main supporting elements of blockchain technology (Adapted from [86])

3.2 Types of Blockchain Technology

3.2.1 Public Blockchain

This type of the blockchain is a network that anyone can join without restrictions. Most types of cryptocurrencies operate on a permission-less blockchain governed by

consensus or rules algorithms [87]. In public blockchains, any individual or entity with access to the network can initiate a transaction and confirm its legitimacy if it adheres to the system's prescribed criteria. In construction sector, public contract applications can be suitable for this type of blockchain technology (BCT), inasmuch as, public blockchain is transparent (Figure 3.3).

3.2.2 Permissioned or Private Blockchain

In the Permissioned blockchain, only authorized participants can join the network (Figure 3.3). However, participation is just by invitation. Transactions can only take place on approved participants, not on every participant [87]. A restricted number of nodes are permitted to retain access, control, and the authority to incorporate transactions into the distributed ledger. The private blockchain network is capable of safeguarding security features, including confidentiality and integrity, to a high degree. Consequently, private blockchain networks can offer reliable business software solutions to the lots of industry.

3.2.3 Federated or Consortium Blockchain

The consortium blockchain does not have a single owner, so it is somewhat similar to a private blockchain. It is a network that allows for the participation of groups of users who have been granted certain privileges. These platforms offer a number of advantages in terms of privacy, efficiency, scalability, and performance, similar to those of a private blockchain. However, a consortium blockchain platform is managed by a group, whereas a private blockchain is managed by a single entity. Furthermore, a consortium blockchain can limit participants to different levels of access, in a manner similar to that of a private blockchain. This blockchain network is closely controlled by a preselected set of nodes or a preselected number of stakeholders in which the mining process [87] (Figure 3.3).

One of the sectors that the developing blockchain technology (BCT) can adapt to is the construction sector. With this technology, we can determine how we will use the accumulated data from the preliminary design stage to the end of the building's life cycle. Blockchain technology is a very important innovation, especially in order to

follow the energy efficiency issue, which is one of the biggest problems of today. BCT will be a very important technology in matters such as the monitoring of the energy produced by the buildings, the list of needs, and if there is unnecessary energy production, its supply to the necessary places.

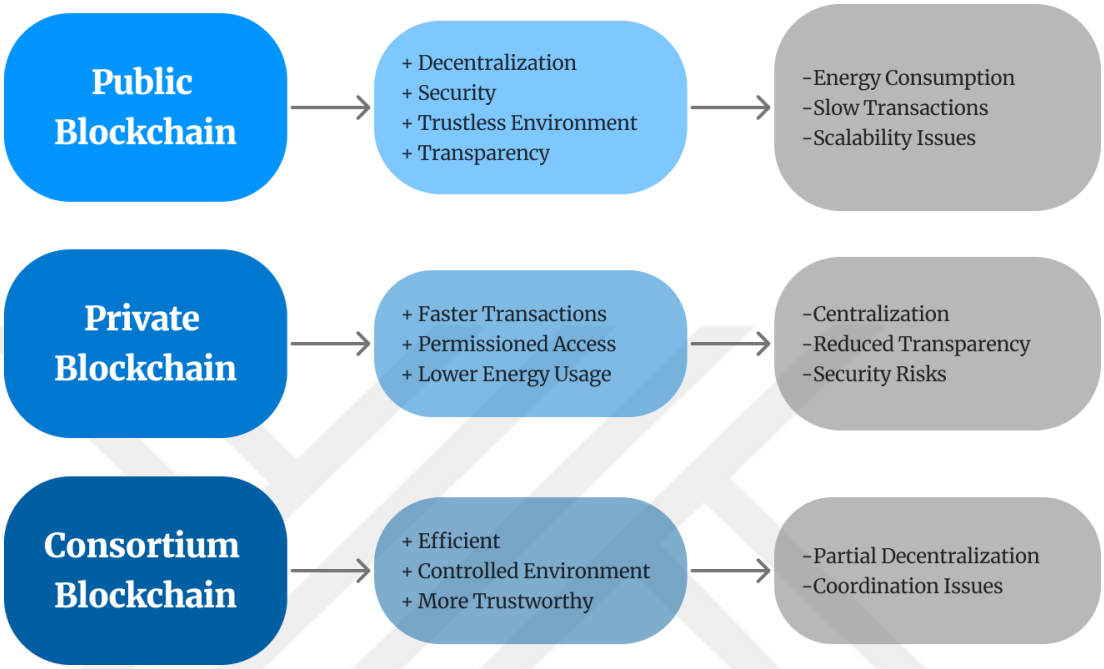


Figure 3.3 Types of blockchain and pros and cons (Created by Author)

3.3 Blockchain Technology Literature Review

The literature has been reviewed and identified nine primary topics of Blockchain Technology. Most of the studies collected were related to payment and finance or supply chain, with the least number of studies focusing on smart grid, education and agriculture. The majority of the studies are review articles that have been published in academic journals. In this section, a detailed literature review has been presented (Appendix B). While there are numerous previous studies on blockchain technology, what sets this study apart is its critical examination of blockchain technology and its applicability to smart building systems from an architectural perspective.

Several prominent studies have explored blockchain technology, with definitions widely available in the literature (Appendix B). [88] presents computer systems and cryptographic techniques that are widely trusted. The paper also highlights the

advantages and includes multiple vault presentations. [89] aim to assess the benefits and drawbacks of incorporating blockchain technology across multiple sectors. The authors explore possible challenges and conveniences of blockchain integration. Key advantages include efficient record-keeping, heightened data security, increased trust, immutability, transparency, and fast processing. High energy consumption, the requirement to use the same forks or software, high costs, and the need for quantitative balance between nodes are drawbacks. [90] provides an overview of the historical background, architecture, manner of work, pros, and cons of blockchain technology in various sectors. The article explores the potential applications of this technology while maintaining objectivity and avoiding biased language. The text is structured with clear progression and causal connections between statements, using simple and concise sentences with precise vocabulary. The author adheres to conventional academic structure, maintaining consistent formatting and style guides, including clear citations and avoiding filler words. The language is formal with no use of contractions, colloquialisms, or unnecessary jargon. The author explains technical abbreviations when first used and aims for grammatical correctness throughout the text. [91] provide an outlook for identifying blockchain algorithms, architecture and security aspects. Analyze comparative framework and this paper discusses in detail future direction and novel using field and research challenges. [92] provide detailed information on the technology's features, structures, mining decisions, forks, and applications. Their goal is to offer technical insight. [93] conducted a comprehensive survey study on blockchain, which outlines blockchain terms, its history, consensus algorithms, cryptography, and smart contracts. The study also provides in-depth information on various security analysis methods. The book provides an in-depth examination of blockchain technology's fundamental principles, elucidating the significance of decentralization, consensus mechanisms, cryptography, and transactions. It also elucidates the practical applications of blockchain in various domains and addresses prevalent misconceptions surrounding this technology [94]. [95] mention the general terminology of blockchain technology and its future prediction, such as blockchain generate as much as $3.1 trillion in new business value by 2030. And practical application of the case across industries.

When investigating the applications of blockchain technology in the payment and finance fields (Appendix B), it is important to note that its inception began with definition of the first electronic peer-to-peer payment system and the introduction of novel keywords such as proof-of-work chain, peer-to-peer, and timestamps for transactions [81]. This paper conducts a comprehensive study in financial and payment contexts and proposes a computational proof solution for maintaining the chronological order of transactions. [96] presented a private smart contract system with a decentralized and defined security protocol in the HAWK program. The paper presents the formal blockchain model's theoretical results as well. [97] presented the main principle of blockchain technology in the financial sector is discussed without detail. Cryptocurrency, bitcoin, coins, tokens, and payment keywords are frequently used. V*italik* Butern's definition is also discussed, and examples of blockchain technology applications are given. [98] a need for new research on the implications and potentials of blockchain technology is also discussed without biased language. [99] analyses the financial and payment-related challenges and regulatory impacts of implementing blockchain technology in the US and EU. Additionally, the paper discusses the practices and views of governments on this issue. [100] discuss the components of blockchain technology and their provisions. Presented is a high-level categorization of private and permissioned blockchain, which includes the definition of architecture, hashes, ledger, and blocks of the blockchain. [101] discusses the implementation of blockchain technology in e-government, specifically in China. The government has attempted to systematize and informatize security, construction, and guaranteed credit. This project aims to solve the problem of individuals' credit by disclosing reliable information about their livelihoods. The advantages of this project align with the national informatization strategy for trade. [102] looking at challenges and opportunities of application of blockchain technology in the banking or finance field and also trying to calculate the total energy consumption of bitcoin. [103] definition journal. In general, it identified blockchain technology, cryptocurrency, distributed ledger technology (DLT), smart contract, BC basis .... [104] created a literature review for future study and its acceptance of finance, marketplace in the blockchain technology. [105] discuss the blockchain technology in the IT understanding and give general information about these keywords. [106] summarise

the BC and DLT literature application in the different cryptocurrencies and payment options. [107] mention the crucial impact of blockchain technology and the general way of life. The paper aims to show the potential in smart contracts, smart cities, digital identity, electronic medical records and IoT. [108] aim to provide a guide about blockchain for a community and individuals. What kind of blockchain, why and how can be used and all this information can be accessed from this paper. The terminology starts with Distributed Legendre Technology (DLT) and goes to the blockchain technology. It also gives information about the main blockchain platforms. This paper contains comprehensive information about blockchain technology, especially in the financial sector. [109] aim to give an overview of working blockchain technology, its types, and its platforms. And also gives some information about the working procedure of blockchain platforms. [110] discuss the impact of the blockchain audit industry and finance sector. [111] analysis of blockchain technology and its advantages and disadvantages and also types in the process of using cryptocurrency. [112] bring clarity fashion of energy consumption of Bitcoin and look beyond these myths. Analyzing the literature review about the energy consumption of bitcoin and alternatives, and observe the close interrelationship between security and choice consensus mechanism and its characteristic, thus energy consumption. In summary, the energy consumption of blockchain technology varies significantly between different types. [113] analyse the public key infrastructure and management for the Bitcoin wallet, and discuss the use of IoT systems in blockchain technology systems. [114] describe blockchain technology and give examples from both financial and non-financial sectors. It also described the risk of adoptions and corporations. [115] present a systematic mapping by collecting all relevant research about blockchain technology. Results show that 80% focus Bitcoin and 20% deal with other fields of blockchain technology.

The studies concerning the use of blockchain in the energy sector, specifically the monitoring of energy production and management, are presented (Appendix B): [116] presented idea of renewable energy generation sources management system with blockchain technology. [117] mentions about energy certification systems and enabling a blockchain system energy efficiency, storage data and trust between stakeholders. [118] provides a proves of blockchain technology fundaments and system structures within the energy sector. [112] bringing clarity fashion of energy

consumption of bitcoin and looking beyond of these myths. Analyzed literature review about energy consumption of bitcoin and alternatives, and observe that close interrelationship between security and choice consensus mechanism and its characteristic, thus energy consumption. To sum up, energy consumption of blockchain technology varies importantly between different types. [119] discuss using blockchain concept in energy management with the circular economy. The aim of the study that shows the contribution of blockchain to a circular economy for energy management. And also, discuss the advantages and disadvantages of these keywords.

The second area where blockchain technology is most applied is supply chain. The studies done on this subject are as follows. [120] conducted a literature review on combating the duplication of permissioned blockchain technology in the supply chain industry. They also analysed the role of BNC, a brand name company, in this combat. [121] aim to present a conceptual framework for integrating blockchain technology to establish a sustainable supply chain system, using the Spherical Fuzzy Analytic Hierarchy Process (SF-AHP) approach. [122] present a review of trends in blockchain technology using logistics and supply chain fields. Inform about blockchain using types and define "register, confirm and transfer any kind of contract and property." Also, the authors talk about blockchain possibilities for BC usage, so they compare it with traditional processes vs blockchain systems. Give some examples about the logistics sector and conclude that BC has huge potential in the supply chain, meaning the logistics sector. [123] encourage blockchain studies in supply chain management and define potential areas of implementation. The conclusion section identifies the lack of literature on operations and supply chain management. A literature review on supply chain management within blockchain technology exists [124]. The review evaluated potential and trends in this area and found that blockchain technology is overgrowing in various industries, indicating vast potential in supply chain management. [125] this article discusses the risks and uncertainties associated with blockchain technology in the supply chain field. It explores concepts such as cryptocurrency, blockchain architecture, as well as supply chain management and its resilience. [126] the paper further examines the potential applications of blockchain technology in the supply chain field. It identifies four barriers hindering the technology adoption and narrows down to the most practical application. [127] additionally, the

study defines various cyber threats to the blockchain system and how it will react. In the conclusion part, BC has several ways of protecting data and processes. However, Intrusion Detection System should improve.

Another potential area for the application of blockchain technology within the agricultural sector is in research studies. This field offers the opportunity to enhance the transparency and trustworthiness of the supply chain, whilst also improving accountability, traceability, and sustainability. Through the use of blockchain technology, it can be possible to track and document each stage in the supply chain, from the farm to the table, thus guaranteeing the safety and quality of the food produced. [128], this survey provides a technical and application overview of blockchain technology in the agriculture. It identifies the data structure, cryptography methods, and consensus mechanisms, categorizes applications through literature reviews, and discusses challenges and potentials. Furthermore, the survey examines how e-agriculture systems could impact the entire sector and play a critical role in addressing the food crisis in the farming industry. [129] investigated the implementation of blockchain technology in agricultural product supply chains, smart farming, and insurance protocols from both a theoretical and practical perspective. In summary, the use of blockchain can enhance food supply chain management and data-driven procedures. Nonetheless, challenges include the motivation of transaction parties and indirect integration with legacy systems.

There have been studies on education, including [130] which provides fundamental knowledge on blockchain technology and its benefits for education. It highlights that the evaluation process is a problematic issue. In addition, [131] critically analyzes the application of blockchain technology's potentials and challenges in higher education.

Studies on the integration of the construction industry, which is the primary objective of this paper, are summarized (Appendix B). [132] provided literature on the potential usefulness of blockchain technology in the construction sector. One prominent application is the blockchain 2.0 "smart contract" which provides insurance contracts. Technical term abbreviations are fully explained when first used. Quotes are clearly marked, and filler words are avoided. Another application is the management and recording of all changes in BIM models throughout the design and construction stages.

Formatting adheres to established style guides and citation practices. [133] the investigation of potential blockchain technology applications in the construction sector reveals that trustworthy supply chain and asset management pose main challenges in this field. Blockchain technology with transparency, immutability, and smart contract principles offers a solution. However, three challenges exist, including technological, construction business-related, and human-related challenges. The author proposes that the combination of BIM and blockchain technology could create a crucial, transparent, and enduring chain. [134] discusses the prevalent issues in the construction industry and how blockchain technology and its historical developments might help address these difficulties.

The following section outlines the focus of this investigation, which is centered on the smart grid and smart building studies. [135] examined how emerging blockchain can aid in the development of smart grids. The investigation employs an evaluation of the human, technological, and organizational aspects of this triangle. From an economic standpoint, blockchain technology can play a vital role in developing smart cities. [136] discuss the security aspect of blockchain in smart cities and smart devices. There are numerous advantages in countering threats and yielding benefits, such as dependable, swift, and efficient operational management, as well as scalability.

The literature about the health sector is vast and diverse. This paper aims to provide an objective overview of current research in this sector, focusing on key areas such as healthcare systems, disease prevention, and public health policy. [137] aim to show that there are numerous starting points for using blockchain technology in the healthcare sector, as well as the potentials, goals, and possible impact of blockchain technology in the healthcare sector. The most crucial aim is fighting counterfeit drugs. [138] discussing the potential impact of blockchain technology in the health field. Privacy and data sharing is the main problem. [139] discuss the “HealthChain” keyword which is a cloud-based application. Describe why blockchain technology should or could be used in the healthcare sector. A person, doctor, insurance company, etc. can observe related things. [140] study blockchain potentials and implementation areas in the health sector, drug supply chain, medicine education, electronic health records, and public health issues. [141] focused on implementing blockchain

technology in the healthcare sector for defining potentials and investigating case studies. This paper also examines interoperability criteria. [142] Discuss the potential of blockchain in the healthcare industry today and its future applications. Mentioned some survey healthcare applications, and results showed that storing all health records in a blockchain interpreted some potential security barrier for implementations. [143] reported a systematic review of using blockchain technology in the healthcare sector. *"The research methodology is based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines and a systematic mapping study process…".* There are some limitations and challenges for blockchain-based healthcare. [144] presented options for using blockchain technology potentials and challenges in the healthcare sector. [145] studied the important benefits of blockchain technology in the healthcare field and defined fourteen implementations. Using clinical trials, record keeping, improving safety, monitoring patients, displaying information and transparency. Keeping records and monitoring is provided that they require data from third parties. [146] a defined gap of blockchain technology in the healthcare industry and its potential E-health systems. [147] provided a literature review about the important role of blockchain technology in the healthcare field with COVID-19. Also, this paper discusses challenges and opportunities in the application examples (collect data with wearable technologies, such as Apple, Google, Amazon Watch, and other vehicle applications).

The law and legality surrounding blockchain technology are of great importance. Several studies have been conducted on this topic. [148] discuss from the legal perspective of blockchain technology. This paper provides different discourses of alegality. To sum up, there is a lack of law in the blockchain technology so this situation is called "alegality". This is true actions are not illegal because there isn't any law or regulator in this field but some actions are not described as legal. Also, this article is funded by the European Research Council under the European Union's Horizon 2020. [149] aim to fill the literature gap and examine such proposals for governmental issues about the blockchain technology. In conclusion, if governments are decentralized, permissioned blockchains probably be more available.

Finally, the studies examined under the heading of IoT are as follows. [150] detected the aspects that need improvement in the architecture of blockchain and IoT systems. The paper also suggested enhancing the efficiency of the integration of BC and IoT. [151] A systematic literature review and bibliometric analysis are combined to define blockchain adoption and its technological development. Web of Science and Scopus databases were used and the date limitation was started in 2015 and the region contains Malaysia. Technology acceptance models are defined in detail and 5 best known theories were used to organize this study. [29] discussing difficulties of security and privacy of data problems in IoT. These papers also mention the primary sources of these problems and the solutions. [152] tried to comprehensively survey blockchain technology and its architecture, potential, and challenges. BC uses lots of fields but privacy and security are controversial topics.

CHAPTER 4

COLLABORATIVE WORK ABOUT THE SMART BUILDING AND BLOCKCHAIN TECHNOLOGY

This literature review encompasses collaborative works and focuses specifically on the keywords "blockchain technology" and "smart building" used in combination. The results of the investigation of seven new studies are presented chronologically (Table 4.3). The majority of these studies are literature reviews from fields other than architecture. This information considers that the study assessed architectural perspective and hardware. [153] have analysed blockchain technology as a smart grid for energy usage in smart homes from a holistic perspective, investigating beyond just energy management and saving in individual homes to a larger scale. In conclusion, their findings indicate that TEM(transactive energy management) based on blockchain can be effectively implemented in practical IoT devices and has the potential to reduce overall costs by 25%. [154] examine the benefits of public and private blockchain technology in smart homes, particularly their ability to secure connections between IoT devices. Ensuring trustworthy devices and connections are essential for smart homes, as is the effective management of data storage to enhance trust and security. The study also confirms the usage of Python 3.7 for blockchain. In summary, the application of blockchain technology contributes to enhancing the security of smart homes when compared to traditional IoT systems. [155] discussed an automated repair system for sensors using smart contract technology. The paper suggested integrating HEPA filters into blockchain technology. Another suggested approach is using Ethereum's architecture, which can be easily implemented on other blockchain platforms. [156] explored the use of blockchain technology in IoT-based supply chain environments. It is shown that this technology has the capability to achieve sustainability and is inevitable. The paper by [157] presents an objective overview of the potential of AIoT-based supply chain architecture. The authors discuss how BIM, IoT, and blockchain technology are employed in smart buildings. Specifically, the paper designs a secure trust management system for HVAC utilizing blockchain technology. [158] conducted a thorough literature review of blockchain technology

integration in smart cities, analyzing its advantages and disadvantages. The topics of reliability, privacy, and accountability were emphasized in the context of smart cities. [159] examined the autonomous dispatching of energy consumption in the smart grid and found, through applied simulation, that it can effectively reduce the cost of distributed energy.

[160] refers to the use of decentralized applications in building management systems. It posits that blockchain technology offers convenient lighting and security monitoring. Consequently, the building can maintain a secure status with decentralised systems, thereby reducing the risk of hacking and increasing the resilience of malicious intruders (Figure 4.1).

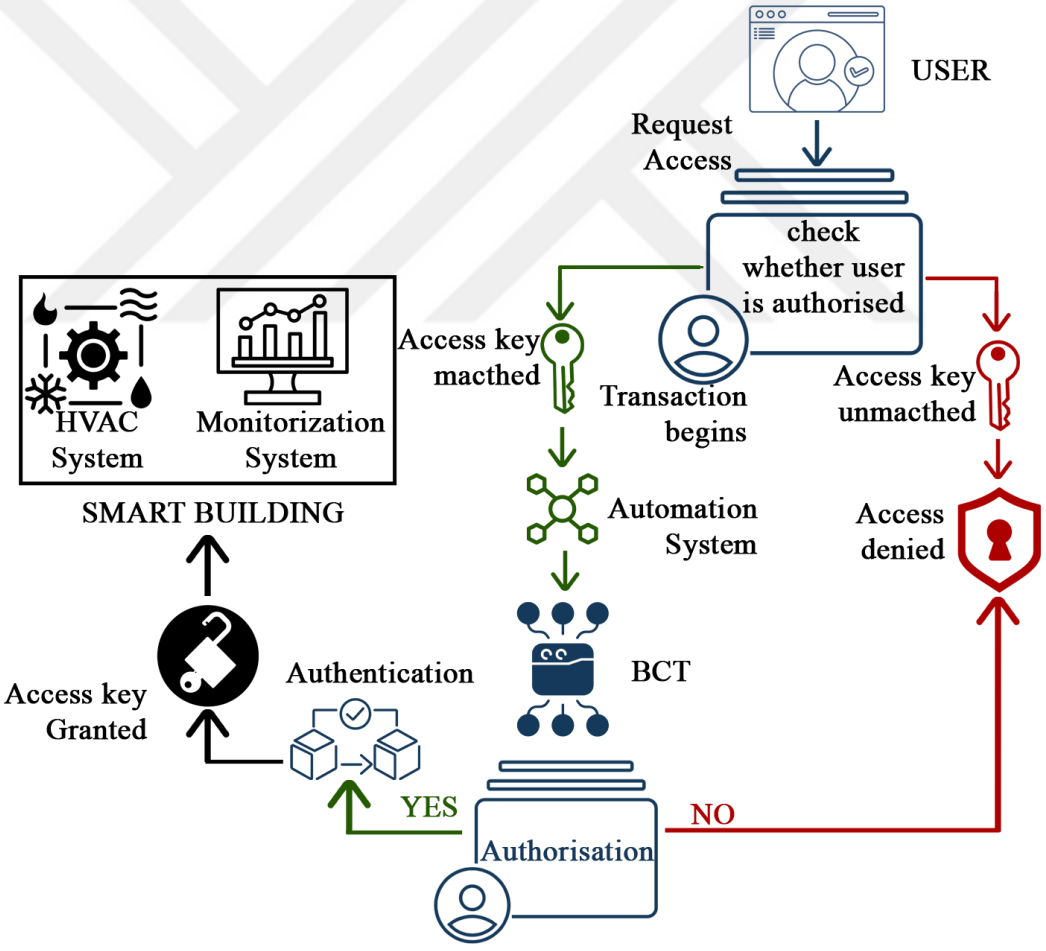


Figure 4.1 Smart Building Implementation System (Adapted by [160])

[161] presents a systematic review of blockchain technology and its potential to enhance sustainability. It examines the core principles of blockchain technology and provides insights into its applications in energy, carbon, and water consumption. It emphasizes the future opportunities for blockchain in supporting circular economies, smart contracts, and data-driven sustainability initiatives, intending to promote more eco-friendly and efficient buildings (Table 4.1).

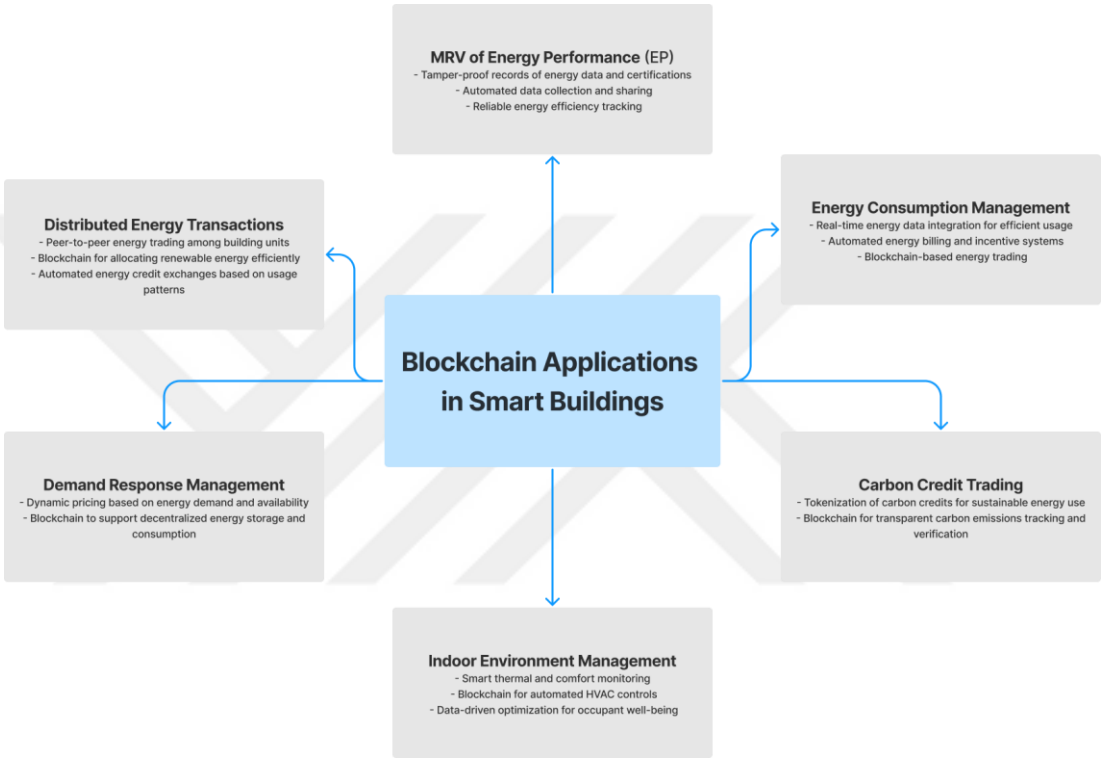


Figure 4.2 Blockchain Applications in Smart Buildings (Adapted by [161])

(Figure 4.2) provides an overview of the diverse applications of blockchain technology in the context of energy management and sustainability in smart buildings. The document identifies potential applications of blockchain technology in the areas of data recording, automation, and efficiency. These include the monitoring of energy performance with MRV (Measurement, Reporting, and Verification), the management of energy consumption, the facilitation of distributed energy trading between building units, the optimization of demand response, the trading of carbon credits, and the management of indoor environmental conditions.

Table 4.1 Blockchain in Key Building Environmental Issues (Adapted by [161])

Environmental Issues	Immutable	Decentralized	Distributed	Automated Execution	Secure	Reliable Research
Energy Management	Immutable records of energy data	P2P energy trading platforms	Distributed energy resources	Smart contract-based energy systems	Tamper-proof energy usage tracking	Active research in energy tokenization and microgrids
Sustainable Materials Sourcing	Immutable supply chain data	Decentralized certification	Distributed verification	Automated material sourcing	Secured supply chain records	Research on sustainable certification (LEED, BREEAM)
Waste Management	Traceable waste data	Decentralized waste tracking	Distributed recycling systems	Smart contract waste reduction	Secured construction waste management	Early-stage studies on blockchain-based waste tracking

Table 4.1 (continued) Blockchain in Key Building Environmental Issues (Adapted by [161])

Environmental Issues	Immutable	Decentralized	Distributed	Automated Execution	Secure	Reliable Research
Carbon Emission Tracking	Immutable carbon records	Decentralized carbon credits	Distributed carbon footprint data	Smart contracts for emissions trading	Secure carbon credits trading	Research on carbon footprint reduction and tracking
Water Management	Immutable water usage data	Decentralized water resource management	Distributed water systems	Automated water management	Secure water resource tracking	Limited research, potential in smart water management
Smart Building Automation	Immutable building data	Decentralized control systems	Distributed building operations	Automated smart building controls	Secure IoT and blockchain integration	Research in IoT integration for smart buildings
Building Lifecycle Assessment (LCA)	Immutable lifecycle data	Decentralized LCA systems	Distributed lifecycle stages	Automated LCA execution	Secure lifecycle traceability	Growing interest in lifecycle data management and sustainability

[162] posits that blockchain technology has the potential to enhance Building Information Modelling (BIM) by providing more secure, transparent, and efficient ways to manage digital data, thereby contributing to the construction industry's shift towards more digitalized processes. [163] Discuss and compare standard SBS and BC system working methods. Digital Twin Asset, Digital Twin Extension, and Blockchain technology terminology are defined in detail. Blockchain and smart building software are discussed. How they work, what is their requirements and questions are answered, and building performance, security, and resilience by linking physical and digital systems securely and efficiently. [164] create a detailed scientometric analysis out blockchain technology and context in smart building. It highlighted essential dates, countries, published journals, and co-occurring keywords. The objective of this paper is to provide an in-depth analysis of the utilization of blockchain technology in the construction industry, with a particular focus on its application in smart projects. Additionally, the research landscape surrounding this field will be examined. [165] analyze electric consumption with a decentralize frame work. Hence, energy trading is smarter with decarbonized gird. Blockchain technology enhances security, transparency, and data integrity in collective building management, improving overall efficiency. This combination addresses scheduling challenges and enhances resource optimization across smart building networks.

Table 4.2 A summary of the literature review about smart building and blockchain technology

Author	Type	General	Review	Scope
[153]	Journal	✓		Discussed as a smart grid with blockchain technology by considering energy use in smart homes from a holistic perspective
[154]	Journal	✓		Discuss public and private blockchain technology in smart home and their advantages with used IoT devices in home connection
[156]	Journal	✓		A discussion of the supply chain environment and the use of blockchain technology in the AIOT context
[157]	Journal	✓		Suggesting trust, securable HVAC managing system in smart buildings
[158]	Journal		✓	Critical analysis of advantages and disadvantages of blockchain technologies on the different field
[159]	Journal	✓		Discussed autonomous dispatching of energy consumption in the smart grid
[155]	Journal	✓		Discussed automatically repair system on the sensors with smart contract way

Table 4.2 (continued) A summary of the literature review about smart building and blockchain technology

Author	Type	General	Review	Scope
[160]	Conference	✓		Explores how blockchain can improve security in smart buildings lighting and monitoring systems
[161]	Journal		✓	Discuss the potentials of the blockchain technology in the sustainability of AEC sector
[162]	Editorial board		✓	Discuss potentials of the blockchain integration of the BIM
[163]	Journal	✓		Explores integrating digital twins and blockchain into smart buildings
[164]	Journal		✓	Create a detailed scientometric analysis about blockchain technology and context in smart building
[165]	Journal	✓		Analyze electric consumption with a decentralize frame work

CHAPTER 5

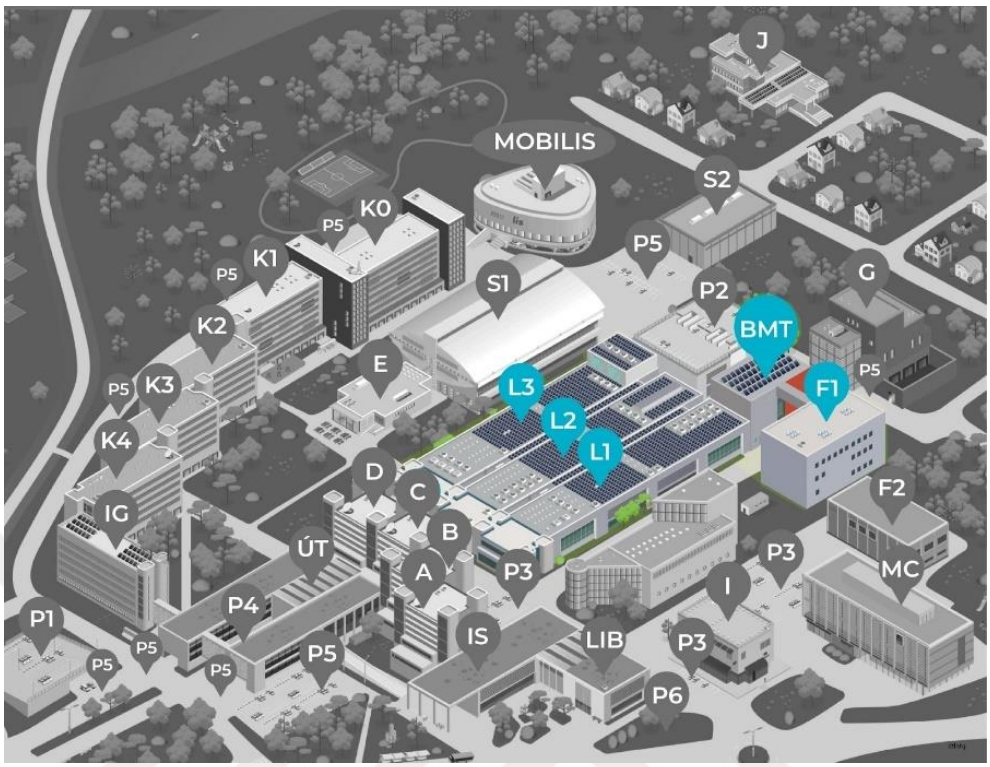
ENERGY MANAGEMENT

Based on the reviewed studies on the mentioned areas, this research evaluates blockchain technology using energy consumption data using a previously collected dataset from a commercial building located at Szechenyi Istvan University Gyor from 2007 to 2024. This industrial building also contains office buildings affiliated with the university. The building has two main centers and three large test laboratory buildings connected to them. Analyzing this building's energy consumption and also potential energy production is an essential methodology of this part. The first section mentions about general presentation on the case study building and university history and the aims of the establishment. The second part of the methodology part is about identifying the components of the building detail. The other part is the investigation of collecting data which is related to energy consumption statistics. The aim of this study, investigate the details of the building features and progress for availability of the blockchain technology.

5.1 Presentation: Case Study; Internal Combustion Engines Department Laboratory Building

Széchenyi István University which was founded in 1968 in Gyor/ Hungary. Until this date, it is studied the higher education instution. The city where the university is located has favorable geographic locations. The Gyor is located between the Hungarian capital of Budapest and the Austrian capital of Vienna. Both have 120 km distances. The other important city is the Bratislava capital of Slovakia which is just 80 km away. The geographic location always brings good relations with the companies. In the 1990s, the first agreement was to partner up an automobile company [166].

Table 5.1 Building Names (Adapted from [167])



a) University Map [168]

Map Indication	Building Name	Map Indication	Building Name
UT	New - Tudástér Building	LIB	University Library
A B C D	Study Buildings	IG	Administration Building
K2 K3 K4	Gyula Hegedűs College	H	INOK - Center For Foreign Language Education
K0 K1	Multifunctional Building	F1	Vehicle Drive Laboratory
BMT	Department Of Internal Combustion Engines And Vehicles Drives	F2	Packaging And Environmental Resistance Testing Laboratory

Table 5.1 (continued) Building Names (Adapted from [167])

Map Indication	Building Name	Map Indication	Building Name
E	"E" Building	J	Deák Ferenc Faculty Of State And Law Building
L1 L2 L3	"L" Lab Building	MOBILIS	Mobilis Interactive Exhibition Center
G	Architect Studio House	IS	INNO-SHARE Building
S1 S2	Sports Halls	MC	Management Campus

Internal Combustion Engines Engineering was established in 2007 (Figure 5.1). The faculty is supported with academic and professional framework thanks to the cooperation with AUDI and the University. AUDI Hungarian Motors, which is subsidized by the German company, has a good relationship with Széchenyi István University [166]. The building aims to provide the workforce with well-trained engineers in the field of combustion engines. The training of successful and qualitative engineers is the first goal of this cooperation. The laboratory gives priority to local suppliers and manufacturers when testing vehicles.

The Internal Combustion Engines Department Laboratory buildings have two floors and the second floor has a bridge for connection between. The area spread could be listed like this; the ground floor has test rooms and laboratory parts, the first floor is using instrumental rooms and the second floor has office parts (Figure 5.2), (Figure 5.3). This building was constructed after the first department building meaning the orange building. The actual testing laboratories are located behind the old building and can be seen on the university map (Table 5.1). The building has some energy management decisions that can related to sustainability. Solar energy, embodied carbon, and passive energy design decisions are some of them.



Figure 5.1 Internal Combustion Engines Department Laboratory Building (Photo by author)

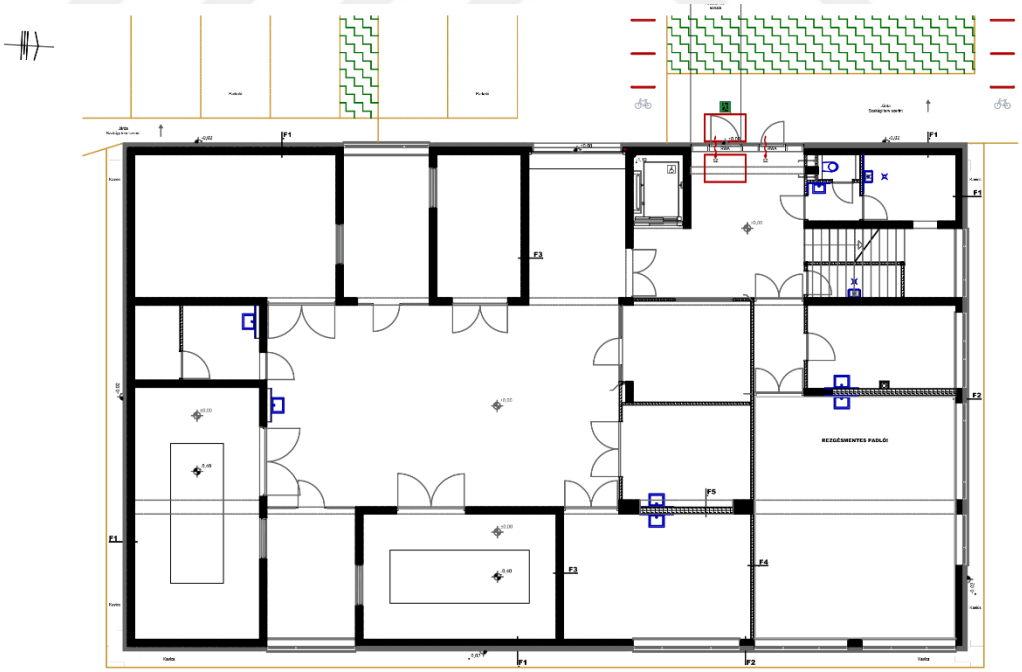


Figure 5.2 Ground Floor Drawing

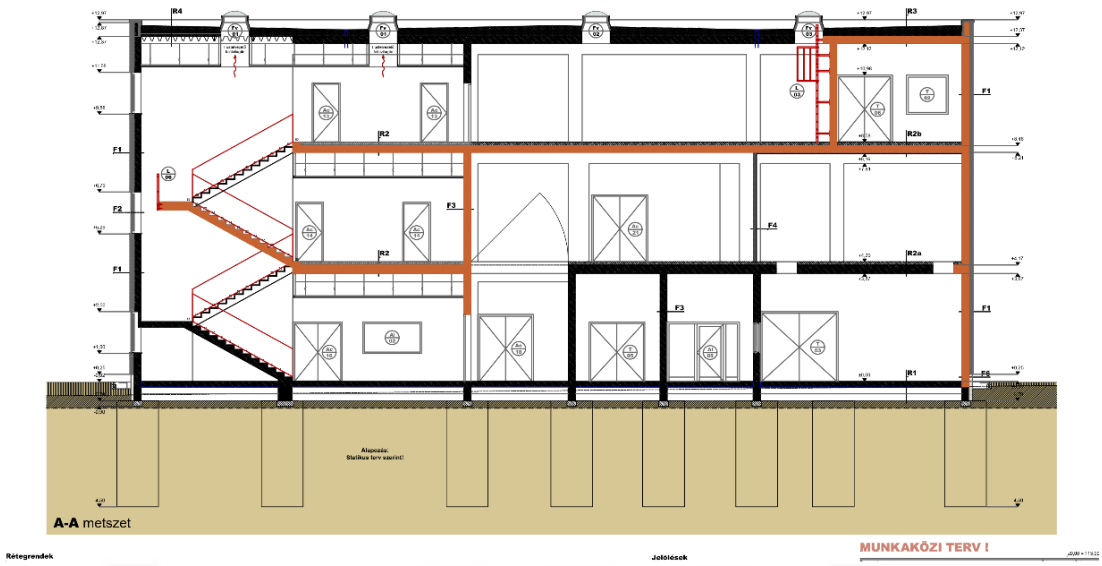


Figure 5.3 A-A Section Drawing

The orange one is the office part and the grey one is the big laboratory and testing part but both are studied together but the grey building was constructed after. additionally, the three real testing laboratories are also working under these two main buildings. In this complex, internal combustion engines are being tested and developed, and as a consequence, a fair amount of energy is emerging.

Excepted from the formal information about this building, a visit was organized to see the real shape of the building. The laboratory building was visited with David Fülöp, the internal combustion engines laboratory's technical manager. According to this face-to-face deep interview, important information about the building was obtained. During the visit these questions are asked;

1. What is the purpose of this building and what kind of system is studying here?
2. What is the building's energy source?
3. What percentage of the energy of the building is provided by the energy panels on the roof?
4. Where is this energy input and through which program is it monitored?
5. For what purposes are sensors used in the building? (fire, lighting, sink, ventilation...)

6. Are there carbon sensors in laboratories? Is this used for occupational health and safety? (carbon poisoning)
7. Is the building smart? If yes, what are the systems used?
8. Have you encountered any security problems before? (physical or cyber attack)
9. This building was established via company funds, does this agreement continue? If the answer is yes, does the funding agency want to see your works, cost, and productions?
10. Would a more transparent monitoring of the work done in this building have a positive impact on the support to be provided to you?

During the visit, something about the sensors is learned. This building has some different sensors from normal buildings and also produces electricity, however, it couldn't be defined smart building due to there being no controlling and monitoring system. CO, CO2, knock, and fire sensors are used in this building that provides indoor air quality and security across the fire, and poisoning. The carbon dioxide sensors and measurement are crucial for this building since, according to the International Energy Agency, the automobile sector is directly accountable for 37% of the world's carbon dioxide emissions which are energy-related [169].

- **Solar Panel:** The first feature is solar energy or solar panels. The building's laboratory roof part fully covered with solar energy panels. It has solar energy panels on the roof and the produced energy is used just for office requirements because this production is less than the consumption and the laboratory and testing room is using more energy. Any program or software does not monitor solar energy panel energy production. The building’s main energy source is the city electric network. The monitorization of the data is significant for the following outputs. However, in this case study structure doesn't have any infrastructure. Mr. Fülöp said that the energy requirement answers the purpose of city electricity hence the solar panels don't work relevant.
- Summer and winter energy consumption production compare: The effectiveness of solar panels varies seasonally, with increased activation during the summer. This is supported by empirical data in (Figure 5.4). However, during the winter months, the available daylight is limited to approximately

eight hours, which is insufficient for solar panels to generate an optimal level of energy output. The seasonal dependency of solar panel efficiency is highlighted by this limitation, emphasizing the need for strategic planning and technological adaptations to address the challenges posed by reduced daylight availability during winter months (Figure 5.4). Therefore, it is imperative to comprehend and address these seasonal dynamics when devising sustainable energy strategies.

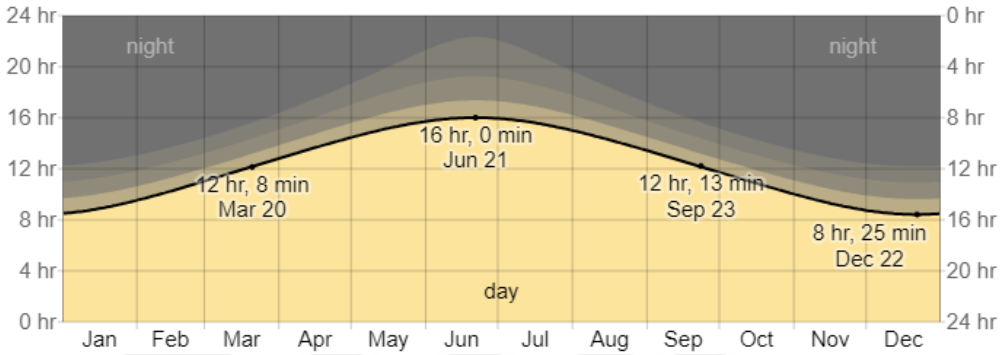


Figure 5.4 Annual sunset time, (taken from [170])

- **Instrument Rooms:** During the building tour, it was revealed that the instrument room (Figure 5.5) occupies a significant amount of space and does not require natural lighting. The room was intentionally isolated from external natural light sources and climatic conditions. The intentional blocking of natural light in these chambers is due to the nature of the activities that take place within them, which do not require daylight. Furthermore, the instrument rooms, which house sophisticated devices, face challenges such as overheating and ambient noise. Consequently, these spaces are intentionally isolated. They employ soundproofing measures and specialized climate control systems to mitigate the deleterious effects of excessive heat and noise generated by the intricate apparatuses housed therein. This strategic insulation ensures optimal operational conditions, safeguarding the precision and functionality of the instruments vital to the facility's objectives.



Figure 5.5 Instrument Room (Photo by author)

- **Testing Room:** The main objective of this project and its departments is to create test rooms. The laboratory building's mission is to educate and train engineers to become experts in their fields. Test rooms are the fundamental components of this building and are designed differently from others due to their specific requirements. They require additional components for testing purposes.
- Testing rooms need voice isolation: The testing rooms are a crucial part of this building complex. Automobile engines are developing here and also testing whole possibilities inside of the rooms (Figure 5.6). For this reason, these areas have extreme conditions which are heat, voice, air conditioning, fire sensors, CO2 sensors… etc. According to the interview, the testing rooms have sound insulation across to high sounds of the engines.

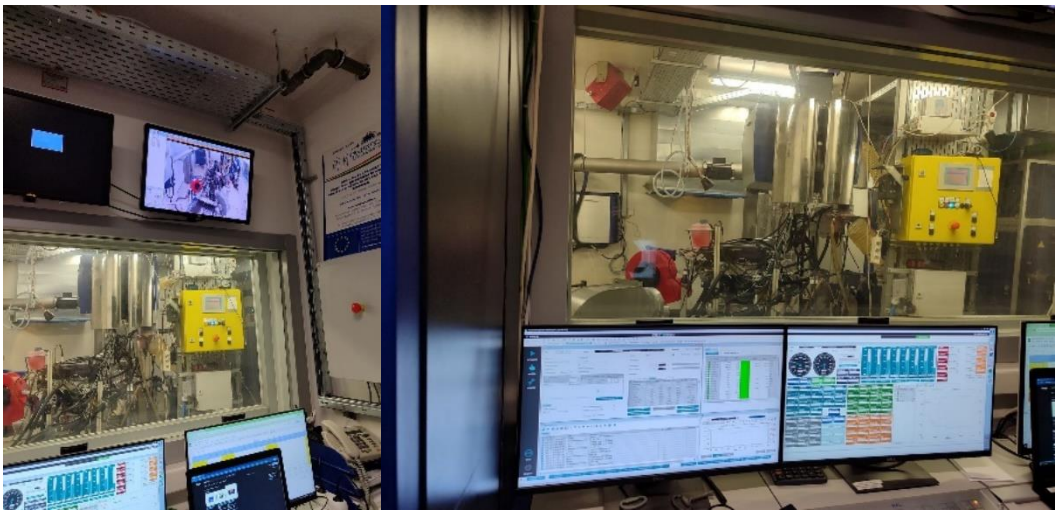


Figure 5.6 Testing Room (Photo by author)

- Testing rooms need a special air conditioning system: The air conditioning system has been crucial for the testing room. All building air conditioning manages normal HVAC systems but testing rooms have addictive air absorbers. Because of this, this building analyzed and developed internal combustion engines and they used fuel, consequently, they produced exhausted gas meaning extra poison CO2. These addictive emission tubes require clean gasses (Figure 5.7).



Figure 5.7 Air conditioning systems inside of the testing rooms (Photo by author)

- Testing rooms need a special fire alarm: Another important point is the special fire sensor named a UV/IR Flame Detector, which aims to detect hydrocarbon-based fuel and gas fires (Figure 5.8). Its working principles sense radiant energy, unlike normal fire detectors. This system is used against any fire or explosion that may occur due to overheating that may occur during or after the test.
- Testing rooms also produce energy: These rooms also produce energy with combusting fuels. This energy is also using the building's electricity requirement. The information from the university's electricity network couldn’t share exact data. Just share that the majority of the electricity used was

generated by the combustion of fuels in the test chambers, while the minor was generated by solar panels.

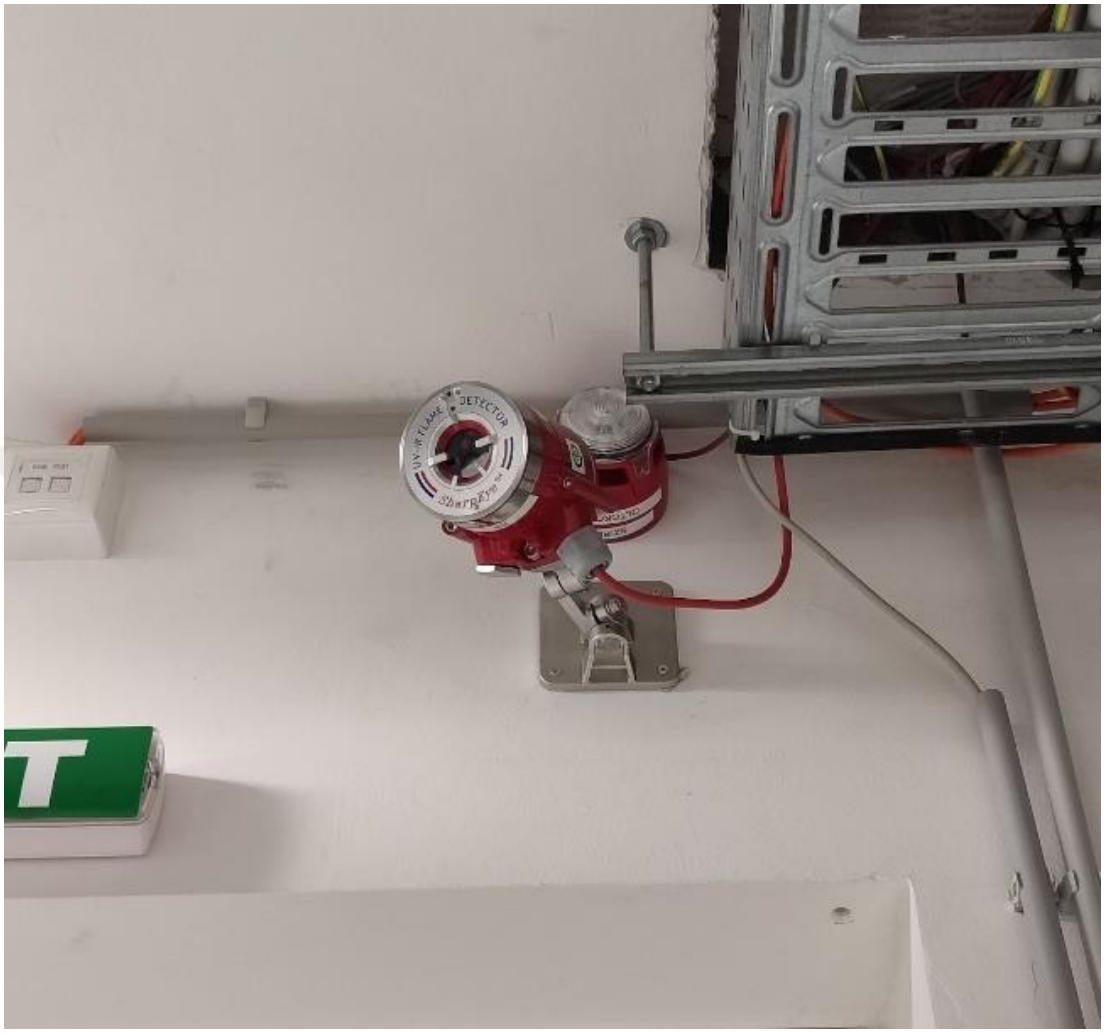


Figure 5.8 UV/IR Flame Detector (Photo by author)

- **Lighting:** For the lighting, just office parts need natural lighting except for office rooms, testing parts, and instrument rooms lighting requirements answer with artificial lighting. Circulation parts have lighting sensors and other parts are controlled manually. The natural light is not just provided on the side window the building also has roof lighting.

Table 5.2 Case Study Building Features and Its Situations

Features	Nowadays Situation	Recommendation	Photo
Solar Panel	The building's laboratory roof part is fully covered and there are some problems with the system. Production and consumption don’t match. Energy suffices just office parts. Produced energy doesn't monitories any of the software.	Blockchain technology network can adapt this building and it can provide these; Monitoring and controlling energy outputs Solar panel companies can control equipment faults	 **a)** Solar Panel (Photo by author)

Table 5.2 (continued) Case Study Building Features and Its Situations

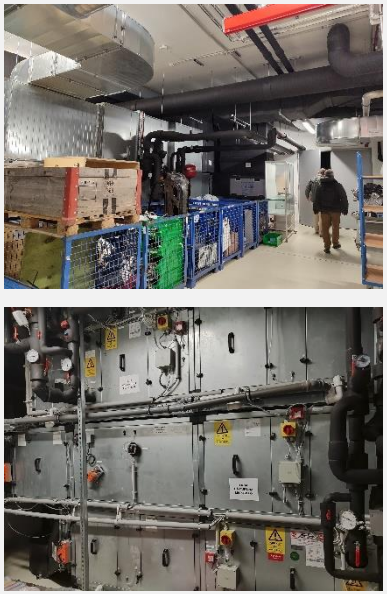
Features	Nowadays Situation	Recommendation	Photo
Testing Rooms Produced Energy	In Audi's test laboratory in the internal combustion engine workshop, energy production from carbon gas is realized with carbon capture and recycling technologies. The carbon captured in this process can be converted into synthetic fuels and reused for energy production, thus reducing emissions and providing sustainable energy. Carbon production and capture is not yet fully understood. The process of energy production is now precise and accurate.	Blockchain technology allows for the straightforward detection of emissions due to the integration of carbon sensors. Furthermore, the production of energy can be monitored through the use of blockchain technology and sensors. This enables the monitoring of passive energy needs.	 **b)** Testing Room Infrastructure (Photo by author)

Table 5.2 (continued) Case Study Building Features and Its Situations

Features	Nowadays Situation	Recommendation	Photo
Air Conditioning	HVAC systems are used in this building. The extra gas absorbers are existing texting rooms for taking CO2 gasses from exhaust.	Blockchain technology can manage The vehicle studies and interferes with any emergency situation. The companies can control technical situations.	 **c)** Air Conditioning Absorber (Photo by author)

5.2 Energy Data Integrity

The Audi Hungaria Internal Combustion Engines Laboratory Building at Széchenyi István University was selected as a case study to illustrate the impact of blockchain integration on energy management in smart buildings. It has been identified as a leading example in terms of energy inputs and outputs (Table 5.2). The building is equipped with three distinct energy sources, namely solar panels, energy generated within the laboratory setting, and the municipal electricity grid. It was not possible to ascertain the inputs and outputs of the system in question, due to the absence of a decentralised, transparent and secure system, such as blockchain. Had a consortium or private blockchain infrastructure been employed for this edifice, it would have been feasible to readily ascertain the quantity of energy consumed from each source and the amount of energy generated by each source. Furthermore, it would have been susceptible to intervention by relevant stakeholders.

5.3 Decentralized Energy Trading

Another proposal, aimed at optimizing the use of resources within the Department of Internal Combustion Engines laboratory, involves the strategic incorporation of blockchain technology. Under this innovative model, the university can leverage its blockchain network to facilitate the efficient rental of laboratory space to external companies, as illustrated in Figure 8. This forward-thinking initiative creates a symbiotic relationship, in which the university gains additional financial resources by charging a reasonable commission for the provision of state-of-the-art laboratory facilities. At the same time, it provides a pragmatic solution for companies, allowing them to conduct comprehensive investigations in a well-equipped laboratory environment without the logistical burden of establishing independent facilities.

The integration of blockchain technology, known for its decentralized and transparent attributes, ensures the veracity and traceability of transactions. This not only promotes secure and auditable exchanges but also builds a foundation of trust between the academic institution and external stakeholders. This strategic collaboration not only increases the financial resilience of the university but also cultivates a dynamic

environment for collaborative research efforts. By positioning itself as a facilitator of industry-academic partnerships, the university reinforces its role as a leader in innovation and knowledge exchange at the intersection of academia and industry. This multi-faceted approach underscores the institution's commitment to fostering an environment supportive of cutting-edge research while enhancing its financial sustainability.

5.4 Energy Monitoring and Optimization

In light of the information obtained, blockchain technology is the most suitable system for this type of grid. Transparent, decentralized, and scalability features are usable for the complex system, and consequently, complexity can provide some benefits. First of all, with blockchain technology solar panel energy production can monitor and spread required fields. Another important recommendation is that the solar panel company also see this data and if there is any technical problem with the solar panels, they can change or repair it automatically. This is also related to the circular economy term. The companies can manage their recyclable types of equipment and the supplier-customer relationship can continue more mutual advantage. This system started to become widespread all over the world. The new one is adapting the blockchain technology.

The second basic suggestion is about lighting and heating infrastructures. For the lighting, automatic control could be suggested. the light measure sensors can be added near the windows and according to the sun circulations, the light level can increase and decrease. Another important part is the detecting person inside the room. If there is no one inside the room, the lighting switch is meaningless. Two options can be present, the first is carbo level measurement, second one is motion sense sensors. Although the need for natural light is high in offices, not many window openings can be used due to the location of the building. This situation makes it difficult to heat the room, especially in winter months.

Blockchain technology can provide for managing HVAC system equipment and vehicle companies can join the blockchain network to see technical controls. It is important to see and test that the devices used are used at full efficiency in terms of energy efficiency. The companies can provide this automatic technical support.

5.5 Integration with Smart Grids

In order to model the interactions between the various stakeholders involved in the management of energy in the context of blockchain technology, the case study building was selected as the conceptual framework for this investigation. The centralised block represents the blockchain technology, which provides a secure storage and sharing environment for energy data (Figure 5.9). In this system, the Audi company, which is a stakeholder in the laboratory, and the university are included in the energy management system via blockchain. Additionally, the network incorporates the city power grid and solar panels as energy sources. This structure guarantees that the laboratory's total energy production, consumption and distribution become more efficient and traceable. The implementation of blockchain technology enhances the security of energy management processes, while simultaneously facilitating enhanced transparency of data and fostering collaboration between stakeholders.

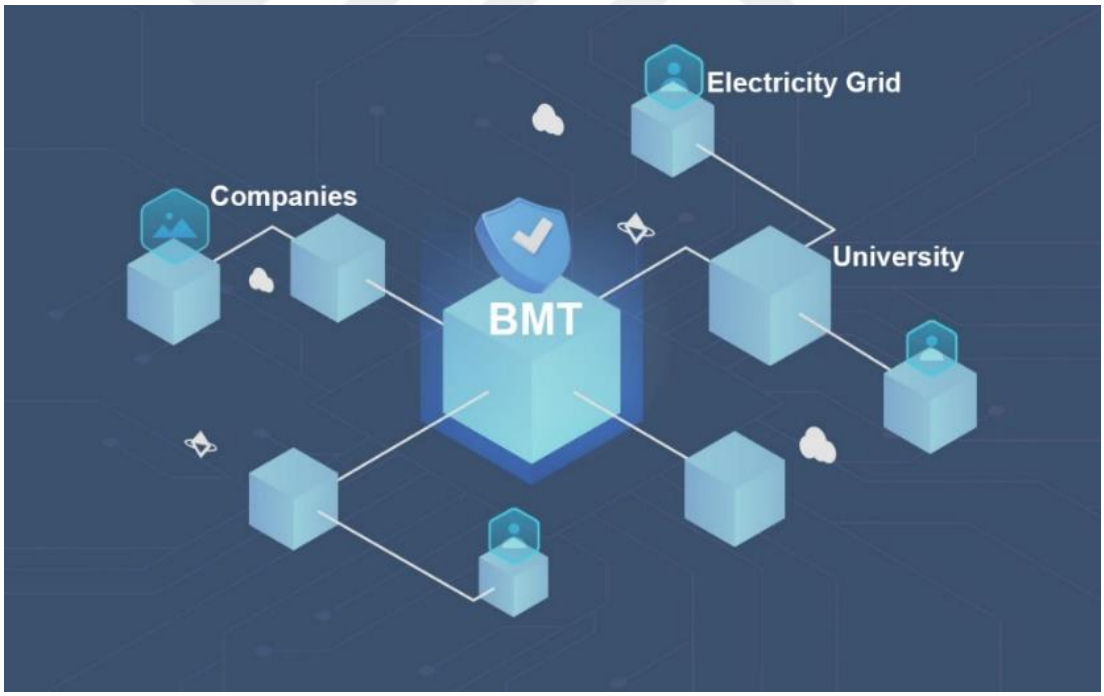


Figure 5.9 Blockchain Technology Network (Adapted by author)

5.6 Security in Energy Management Systems

Security in energy management is critical, especially in structures that work with distributed energy sources such as smart buildings and renewable energy systems.

Blockchain technology offers a powerful solution to meet this security need. Blockchain-based systems ensure that energy data is kept in a decentralised structure, minimising potential data breaches and cyber-attacks. Since every transaction is transparently recorded and irreversible, all information about energy consumption and production is secured. In this way, the occurrence of security gaps in energy management processes is prevented, while data integrity between energy users and providers is also protected. Especially in ecosystems involving different stakeholders such as companies and university laboratories, blockchain technology protects sensitive data against unauthorised access.

CHAPTER 6

RESULTS

Expanding on the results of our comprehensive analysis, which examined 58 articles on smart buildings, 65 articles focused on blockchain technology, and a mere seven articles exploring collaborative keywords, a nuanced understanding of the prevailing gaps in the literature arises. It is noteworthy that a cluster of 13 articles, among the total of 136 publications reviewed, intersect both blockchain technology and smart buildings. Upon further examination, only seven of these articles specifically cover the intersection, indicating a more concentrated yet restricted discussion on the connection between these cutting-edge fields. Additionally, a significant contrast is present in the civil engineering department's low representation of architecture, with only 13 articles directly relevant to this discipline. The discovery suggests that there may be a shortage of research output and professional involvement in the architecture and construction industry which requires further investigation and consideration. Furthermore, analysis highlighted a common pattern where many studies in this field mainly rely on literature reviews instead of offering innovative concepts. This emerging trend calls for further innovative research to advance the discourse. Although the subject has various applications, it is evident that the primary resonance lies within the supply and energy sectors.

The critical research revealed significant shortcomings in the traditional infrastructure systems and interfaces employed in smart buildings for remote control. These systems and interfaces are particularly vulnerable to security breaches. The identification of such issues highlights the necessity for significant enhancements to be made to the existing control and management methodologies currently employed within smart buildings. The objective of the present study is to demonstrate how energy management in smart building systems can be optimised through the implementation of an integrated and decentralised control approach. From this perspective, the definition of the decision problem must be as precise as possible.

At the Problem Definition and Model Establishment stage, particular attention was paid to the security vulnerabilities associated with energy management and the shortcomings inherent to the prevailing central control systems. In this context, three key areas were identified for further investigation: the dependability of energy management in smart buildings, the integration of systems, and the decentralisation of control structures. Subsequently, the sub-criteria were organised into categories pertaining to data integrity, security vulnerabilities and the constraints of the central control structure. Furthermore, alternative solutions were sought wherever possible in order to align with the aforementioned sub-criteria.

In light of the above, the extant literature posits that blockchain technology represents a highly promising avenue for further enhancements to the architectural framework of a smart building. Blockchain technology represents a promising avenue for enhancing the security and decentralisation of energy management systems. It offers a solution that is simultaneously reliable, authenticating, and authorising. Given its intrinsic characteristics, blockchain represents a valuable enhancement to the shortcomings of a centralized system. It offers a high degree of data integrity, coupled with a reduction in security vulnerabilities. Indeed, this would have a transformative impact on the energy management of smart buildings, which offers a more reliable, scalable, and integrated solution than what could be achieved through centralized approaches. In light of these considerations, it was concluded that the structure of a smart building could be optimised in terms of security and sustainability by integrating blockchain

technology into the energy management systems of the model developed as a result of the research.

In the process of evaluating the results found in the literature, it was determined that the Analytic Network Process (ANP) was the most appropriate method for achieving the desired outcome. The varying importance of criteria such as building size and need status in these systems demonstrated the necessity for a non-hierarchical evaluation method. This reinforced the conclusion that ANP was the most appropriate method to meet these needs.

The internal and external dependencies pertinent to the process of decentralising energy management and enhancing security in smart buildings were identified herein. Subsequently, the interrelations between the principal criteria of reliable energy management, system integration and decentralised control structures were examined. For example, there is a direct correlation between the direct treatment of security vulnerabilities and the integrity of data. Furthermore, system integration was identified as a crucial factor in ensuring the reliability of decentralised systems. In developing a more comprehensive model, the feedback from the evaluation criteria was also taken into account.

At this stage, the study carried out pairwise comparisons between the main criteria of reliability, integration and decentralisation and the sub-criteria of data integrity, security vulnerabilities and limitations of central control structures. In order to determine the relative importance, the relative importance of each criterion and sub-criterion was calculated. For example, it would be of great interest to observe the relative importance of preventing security vulnerabilities versus maintaining data integrity in energy management processes. Since the weights were assigned based on the results of the pairwise comparisons mentioned above, it was determined which criteria were prioritised.

Table 6.1 Pairwise Comparison Matrix

	Reliability	**Integration**	**Decentralization**
Reliability	1	3	2
Integration	1/3	1	½
Decentralization	1/2	2	1

Based on the results of the pairwise comparisons, a comparison matrix (Table 6.1) was created and analysed. The weights of each criterion were obtained after normalising the columns of the matrix (Table 6.2). In order for these weights to be reliable, it was necessary to check the consistency of the comparison matrix. It was then checked for consistency and no inconsistencies were found. The constant comparison matrix provided the transparency needed to assess the influence of each criterion in the model.

Table 6.2 Normalized Matrix

	Reliability	**Integration**	**Decentralization**	**Row Avarage**
Reliability	0.60	0.60	0.50	0.57
Integration	0.20	0.20	0.25	0.22
Decentralization	0.20	0.40	0.25	0.31

This step created the supermatrix to reflect the long-term relative importance of the criteria and sub-criteria in the model (Table 6.3). As it is a partitioned matrix, the supermatrix reflects the internal relationships of each two different pairs of criteria. To ensure that the weights stabilise over time, the power of the supermatrix was raised to a power of (2n+1), where n is an arbitrarily large number chosen at random. This would give the resulting matrix, which is the 'limit supermatrix' that can be used to find the relative importance of the criteria on the decision over the long term. It describes how the criteria interact over time, security, decentralisation and integration, and their relative importance in the energy management of intelligent buildings.

Table 6.3 Supermatrix

	Reliability	**Integration**	**Decentralization**	**Data Integrity**	**Security Vulnerabilities**	**Limitations of Central Control**
Reliability	0.20	0.3	0.2	0.1	0.1	0.1
Integration	0.20	0.30	0.2	0.2	0.05	0.05
Decentralization	0.20	0.10	0.30	0.15	0.15	0.1
Data Integrity	0.30	0.20	0.15	0.25	0.05	0.05
Security Vulnerabilities	0.20	0.10	0.20	0.10	0.20	0.20
Limitations of Central Control	0.10	0.05	0.10	0.10	0.30	0.35

CHAPTER 7

CONCLUSION AND DISCUSSION

The integration of blockchain technology in smart buildings is becoming increasingly inevitable, driven by a surge in research and development addressing various architectural concerns. These include, but are not limited to, energy management, financial transactions, supply chain optimization, and advancements in construction technologies. Blockchain offers a decentralized and secure framework that enhances transparency, efficiency, and accountability. For instance, energy management systems can leverage blockchain to facilitate peer-to-peer energy trading, while supply chains can benefit from enhanced traceability and fraud prevention. Consequently, the convergence of blockchain technology with smart building systems promises to revolutionize the architecture industry by fostering more sustainable, efficient, and resilient infrastructure (Table 7.1).

Table 7.1 Using blockchain technology in smart building advantages and disadvantages

Advantages	**Disadvantages**
Data security and transparency	High energy consumption
Increase the efficiency	Costs
Renewable energy integration	Regulatory Barriers
Confidentiality of user data	Technological complexity
Monitorization	Data speed
Decentralization	Compliance and integration challenges

Recent developments in the domain of blockchain technology have inspired this project, which examines the effects of industrialisation on the world and humanity, and explores the application of blockchain technology in smart buildings. This study discusses integrating Blockchain technology into smart buildings by customising the general concept of smart devices. The literature review includes the latest articles and technological developments, providing a comprehensive analysis of the current situation. The insights offer a framework for future work aimed at addressing the identified gaps, promoting the intersection of smart buildings, blockchain technology and architectural considerations in the construction industry. The systematic literature review presents significant insights for informing future studies. The findings from this initial investigation suggest that examining integrating of blockchain into smart building systems, specifically within the domain of energy management, could enhance operational effectiveness. The review recommends that these particular keywords such as life cycle assessment, circular economy, and green building are best suited for interlinked subject matters.

7.1. Limited Research on Integration

- **Gap**: One of the most significant challenges encountered in this study on the integration of blockchain technology in smart buildings has been the dearth of comprehensive research on the subject matter. In particular, there is a notable scarcity of studies from the field of architecture, which represents a significant gap in the existing literature.
- **Opportunity**: The paucity of new studies and research in this field has elevated the originality of this thesis study. In the domain of architecture, this study will elucidate future avenues of inquiry and delineate the pivotal elements to be prioritised when developing a blockchain environment.

7.2. Real-World Case Studies

- **Gap**: As can be observed from the data presented in Tables 2.2, 3.1 and 4.2 of the literature review, approximately 80% of the published studies were review studies and did not include case studies. This lack of empirical evidence precludes an understanding of the potential outcomes of implementing a highly

successful system in real-world contexts, particularly in relation to the human factor.

- **Opportunity**: The Audi internal combustion engine laboratory building is an industrial structure that contains a multitude of sensor data and generates its own energy source. The data obtained from the relevant authorities is insufficient for us to define the building as a smart building. However, it is evident that despite the presence of substantial data input and output within the building, there is a lack of a system capable of being monitored. In light of the fact that this building requires stakeholders, security measures and energy management, it is clear that the characteristics of blockchain technology will align perfectly with its needs.

7.3. User Experience and Engagement

- **Gap**: There is currently no research available that assesses the impact of blockchain-based energy management systems on user experience and interactions. This raises the question of how these systems affect users' energy usage habits, energy efficiency awareness, and their interactions with these systems. It is evident that there is a need for further studies in this area.
- **Opportunity**: It would be beneficial to examine how architectural design can enhance user interaction with these systems. At this juncture, it would be advantageous to investigate how to integrate energy management systems into smart buildings and how building design can facilitate greater user interaction with these systems. For instance, user interfaces in buildings (devices, screens, etc. where users can monitor and manage energy consumption) or architectural features can be designed in a manner that encourages energy efficiency.

7.4. Interdisciplinary Approach

- **Gap**: The incorporation of blockchain technology into smart buildings is becoming an increasingly compelling necessity, as evidenced by the growing body of research and development addressing a range of architectural concerns. Such applications include, but are not limited to, those pertaining to energy management, financial transactions, supply chain optimisation, and

developments in construction technologies. Blockchain provides a decentralised and secure framework that enhances transparency, efficiency and accountability in these domains. To illustrate, energy management systems can utilise blockchain to enable peer-to-peer energy trading, whereas supply chains can gain from enhanced traceability and fraud prevention. Eventually, the integration of blockchain into intelligent building systems could prove to be a transformative development for the architectural industry, facilitating the creation of infrastructures that are more sustainable, efficient, and resilient.

- **Opportunity**: The research will adopt a holistic approach, bridging the gap between architecture, technology and sustainability. It will provide a comprehensive perspective, elucidating the interconnections between these domains.

7.5. Blockchain's Role in Sustainability

- **Gap**: There are several significant gaps in the existing literature on blockchain technology and sustainable architecture. These include the absence of holistic case studies, a lack of analysis of user interaction and behaviour, a dearth of research on regulatory frameworks and standards, the failure to incorporate energy management, and a paucity of economic and environmental cost analyses. There is a paucity of real-world application examples, and a need for a more in-depth examination of the long-term benefits of blockchain. Furthermore, there is a paucity of research examining the potential for integrating blockchain technology with architectural design to enhance energy efficiency and achieve sustainability goals. These gaps demonstrate the necessity for further empirical studies and more economic analyses to fully comprehend the technology's influence on architectural projects.
- **Opportunity**: Blockchain technology enhances transparency and reliability in building operations by enabling the monitoring of performance metrics such as energy use, materials employed, and carbon footprints. These sustainability indicators should be subject to regular monitoring. To illustrate, blockchain-based systems record energy data from buildings in a secure and immutable manner, thus facilitating the achievement of sustainability goals or monitoring

compliance. Furthermore, this technology automates processes related to energy efficiency and carbon reduction through the use of smart contracts in the context of renewable energy production and sharing. Blockchain technology also enables the tracking of material supply chains, thereby ensuring the use of sustainable, certified materials. Consequently, environmentally friendly and efficient buildings can be designed with secure data management and innovative energy management systems in sustainable architecture.

7.6. Comparative Analysis

- **Gap**: A review of the literature reveals a dearth of studies that directly compare the impact of blockchain technology on energy efficiency in smart buildings with that of other systems. Discussions have been held regarding the prevalence of cloud-based integrated systems in smart buildings and the advantages and disadvantages associated with such systems. However, there is a notable absence of empirical studies that directly assess the relative merits of cloud-based and blockchain technology in the context of smart buildings.
- **Opportunity**: One of the research questions addressed in this study is to identify the distinctive features of blockchain technology and to ascertain its potential contributions to the domain of smart buildings. In summary, the integration of blockchain technology, the absence of inherent security weaknesses and the adoption of a decentralised data management approach collectively support the management and users of smart building systems.

The study addresses a novel topic, namely the utilisation of blockchain technology in smart buildings. Given the paucity of prior research on the integration of blockchain technology and smart buildings, the study makes a notable contribution to the existing literature in this field. It offers a comprehensive literature review and an in-depth examination of a case study focusing on energy efficiency. The application of the ANP method to the criteria extracted from the comprehensive literature analysis offers a distinctive methodological contribution to the existing literature on literature review studies. In particular, it addresses the analysis of non-hierarchical criteria in the context

of building and energy management. Furthermore, this can serve as an exemplar in terms of research methods. The case study on the efficient integration of energy management and smart building systems provides valuable insights into the sustainability goals of such systems. It also offers a basis for future studies that will evaluate these two concepts together. This thesis provides a theoretical foundation for future large-scale application studies. In particular, it offers a guide for those who want to investigate the use of blockchain in smart buildings by creating an infrastructure for applied studies.

The life cycle of a building can be divided into three fundamental phases: the construction phase, the usage phase and the post-use evacuation phase. The Building Information Modelling (BIM) system, which enables stakeholders to collaborate in a shared digital environment during the construction phase, is currently being utilised and has demonstrated considerable success. However, one of the inherent limitations of this approach is the inability to track financial payments and energy exchange. In the second phase, namely the building usage phase, while a smart building is being designed, the systems are cloud-based systems, and their issues have been discussed throughout this thesis. In the final phase, the recycling evacuation phase, processes such as the detection of each of the components used by the relevant unit and the subsequent action can again be provided with blockchain technology. It is evident that this study will inform future studies not only during the usage period of smart buildings but also throughout their entire lifespan.

CHAPTER 8

FUTURE STUDIES

It is anticipated that the pervasive integration of blockchain technology within building management systems will facilitate substantial enhancements in a number of critical domains, including energy management, security, data privacy, and resource optimization. The decentralized structure of blockchain facilitates data integration between building systems, enabling the secure and unalterable storage of information. Consequently, it will be feasible to conduct transparent monitoring and management of processes such as energy production and consumption. This technology has the potential to enhance operational efficiency, not only in energy management, but also by enabling the integrated and reliable operation of different systems within the building. Furthermore, the use of smart contracts in energy trading allows for transactions to be conducted in an autonomous, secure, and traceable manner. In future studies, blockchain technology is anticipated to be combined with the Internet of Things (IoT) and artificial intelligence, thereby contributing to the creation of fully integrated, secure, and transparent smart building systems. Although this study provides evidence of the potential advantages of blockchain technology in smart buildings, it also highlights the necessity for further investigation into the domains of energy management and security. It is anticipated that future studies will enhance the theoretical and practical framework on this subject and offer innovative solutions for the sector.

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APPENDICES

Appendix A: Smart Building Litarature Review

Appendix B: Blockchain Technology Litarature Review

Appendix A- Smart Building Literature Review

Table A.1 A brief summary of the literature review about smart building

Field	Author	Type	General	Review	Scope
Energy Management	[51]	Conference		✓	Aimed to provide a general literature review about smart building energy managing.
	[50]	Journal		✓	Compared occupant-centric and energy or device-centric solutions machine learning based.
	[52]	Journal		✓	Offering a thorough and extensive review of literature on the application of deep reinforcement learning to smart building energy management.
	[37]	Conference	✓		Presented how to build and use a low-cost, battery-powered, distributed occupancy system.
	[45]	Journal		✓	Presented a platform-based methodology and defined components

Table A.1 (continued) A brief summary of the literature review about smart building

Field	Author	Type	General	Review	Scope
Energy Management	[39]	Journal		✓	Aim that calculate energy consumption in the smart home with using mixed integrated linear programming (MILP)
	[38]	Journal		✓	Analysis and comparison of the energy storage performance of various vehicles.
	[42]	Journal		✓	An agent-based strategy has been suggested to enhance the interoperation of smart grid/building energy management systems.
	[43]	Journal	✓		Presented DC distribution systems for using smart houses energy efficiency field.
	[46]	Journal	✓		Aim a new deep learning estimation for control energy usage of a smart building.

Table A.1 (continued) A brief summary of the literature review about smart building

Field	Author	Type	General	Review	Scope
Energy Management	[44]	Journal	✓		Aim a new framework for commercial building two-level grid to manage energy.
	[41]	Journal		✓	Analyzing SBEMS vs conventional BEMS.
	[53]	Journal	✓		Focus energy consumption predictions with using ML.
	[54]	Journal	✓		Presented a novel model of energy management based on the new model.
	[47]	Journal	✓		Demonstration of the use of transfer learning in the development of an intelligent human counting system.
	[48]	Journal	✓		Mention about smart home (SH) energy management and risks and consumptions using devices in smart homes
	[49]	Journal		✓	Aimed that presented types of smart home technology

Table A.1 (continued) A brief summary of the literature review about smart building

Field	Author	Type	General	Review	Scope
Energy Management	[55]	Journal		✓	Deep review of AI technology of smart home for smart building management systems
	[56]	Journal		✓	Investigating ways of smart grid promoting energy sector
	[57]	Journal		✓	Discussing 5G technology in the smart building examples in Singapore
	[40]	Conference		✓	Analyze the device-to-device communication with using ZİGBEE protocol.
	[48]	Journal	✓		Study in the effect of smart home devices on cyberattacks and some consumptions
	[34]	Journal		✓	The energy efficiency potential of smart city concepts is discussed.

Table A.1 (continued) A brief summary of the literature review about smart building

Field	Author	Type	General	Review	Scope
Sensor	[72]	Journal		✓	Discussed types of sensor systems and using fields and contributions to smart building indoor environmental quality.
	[71]	Journal	✓		Focused automation systems for energy management. Proposed some alternative system for this.
	[65]	Journal	✓		Impacts of pandemic situations of building consumption habits.
	[73]	Journal	✓		Present a software for managing smart buildings with digital twin
IoT	[66]	Conference		✓	Aiming new and effective smart home controlling system from smartphone.
	[62]	Journal		✓	Discussed emerging implementation of features and controlling parameters and IoT infrastructure.

Table A.1 (continued) A brief summary of the literature review about smart building

Field	Author	Type	General	Review	Scope
IoT	[68]	Conference	✓		Proposed measure the blockchain technology for the security and control framework with BIM and IoT keywords
	[67]	Conference		✓	Presented some definitions of IoT, WIFI, zigbee… and how the sensor technology can develop in typical apartment monitoring
	[70]	Journal	✓		Define a SDN based IoT control and management system for smart buildings.
	[77]	Journal	✓		Describe application and design of IoT meaning cloud base BEM system
	[69]	Journal		✓	Focusing detailed literature review about optimization of energy consumption in smart home.
	[49]	Journal		✓	Aimed those present types of smart home technology

Table A.1 (continued) A brief summary of the literature review about smart building

Field	Author	Type	General	Review	Scope
IoT	[57]	Journal		✓	Discussing 5G technology in the smart building examples in Singapore
	[9]	Journal		✓	Aim to discuss IoT and adapt technologies of smart home
Remote Control	[58]	Conference		✓	Providing a perspective of a software system to improve energy management in the buildings.
	[18]	Journal		✓	Examine literature for SBEMS and explore future study
	[62]	Journal		✓	Discussed emerging implementation of features and controlling parameter and IoT infrastructure.
	[60]	Journal	✓		Suggest a new management system for smart building.
	[63]	Journal	✓		A real-time control system for smart buildings has been proposed.

Table A.1 (continued) A brief summary of the literature review about smart building

Field	Author	Type	General	Review	Scope
Remote Control	[59]	Conference	✓		Suggested IoT-based approach for controlling in the smart buildings
	[61]	Journal	✓		Paper mentions about novel technology that name is OCTOPUS about controlling energy management.
	[65]	Journal	✓		Impacts of pandemic situations of building consumption habits.
	[64]	Journal	✓		Present a new process for collecting and contextualizing two important types of POE
	[9]	Journal		✓	Aim to discuss IoT and adapt technologies of smart home
Blockchain Technology	[68]	Conference	✓		Proposed measure the blockchain technology for the security and control framework with bim and IoT keywords

Table A.1 (continued) A brief summary of the literature review about smart building

Field	Author	Type	General	Review	Scope
Blockchain Technology	[70]	Journal	✓		Define an SDN based IoT control and management system for smart buildings.
	[74]	Journal		✓	Study in aspect linked to the application of smart grid citizens.
Smart Grid/ City	[75]	Journal		✓	Aim that explain the features of the smart building and compare with the smart city context.
	[42]	Journal		✓	Proposed an approach agent-based for optimizing the interoperation of the smart grid/ building energy management system
	[76]	Journal		✓	Discussed nowadays application of the smart building and status of IoT in the smart city context
	[56]	Journal		✓	Investigating ways of smart grid promoting energy sector

Table A.1 (continued) A brief summary of the literature review about smart building

Field	Author	Type	General	Review	Scope
Smart Grid/ City	[57]	Journal		✓	Discussing 5G technology in the smart building examples in Singapore
	[34]	Journal		✓	The energy efficiency potential of smart city concepts is discussed.
	[74]	Journal		✓	Study in aspect linked to the application of smart grid citizens.

Appendix B- Blockchain Technology Literature Review

Table B.1 A brief summary of the literature review about blockchain technology

Field	Author	Type	General	Review	Scope
Payment **Finance**	[108]	Journal		✓	Created an extensive guideline about blockchain technology; answered when, which, and how questions.
	[97]	Journal		✓	Exposed some core concepts of blockchain technology and its applications
	[107]	Conference		✓	Aimed that show potential blockchain technology in the finance sector and many fields
	[109]	Journal		✓	Aimed to provide a general overview of blockchain technology
	[98]	Journal		✓	Need for detailed research of blockchain technology potential and implementation

Table B.1 (continued) A brief summary of the literature review about blockchain technology

Field	Author	Type	General	Review	Scope
Payment **Finance**	[99]	Journal		✓	Examined the key regulatory difficulties impacting blockchain US and EU
	[112]	Journal		✓	Bringing clarity energy consumption of Bitcoin and looking beyond these myths
	[101]	Conference	✓		Discuss the implementation of blockchain technology in e-government, especially in Chinese
	[102]	Journal	✓		Looking challenges and opportunities of the application of blockchain technology in the banking or finance field
	[113]	Journal		✓	Analyzing public key infrastructure and management for Bitcoin wallet
	[103]	Journal		✓	Presenting definition of the blockchain, DLT, chain, transparency, and related terms.

Table B.1 (continued) A brief summary of the literature review about blockchain technology

Field	Author	Type	General	Review	Scope
Payment **Finance**	[100]	Journal		✓	Aim that describe how BC works and discuss categories and potentials of BC.
	[104]	Journal		✓	Creating review for future study using of blockchain technology.
	[105]	Journal		✓	Discuss general information about blockchain technology inside IT.
	[106]	Journal		✓	The goal is summarized in the literature application in this paper.
	[110]	Journal		✓	Discuss how blockchain will impact of finance and audit industry.
	[111]	Journal		✓	Analysis of blockchain technology and its pros, cons, and types in the crypto-currency transactions.
	[81]	Journal	✓		Define the first peer-to-peer electronic cash and online payment system.

Table B.1 (continued) A brief summary of the literature review about blockchain technology

Field	Author	Type	General	Review	Scope
Payment **Finance**	[96]	Journal	✓		Presented a smart contract system with decentralization and defined security protocol.
Supply chain	[121]	Journal	✓		Aims to recognize the interdependencies. Between the challenges for new mathematical models (blockchain) supply chain
	[122]	Journal		✓	Give information about blockchain technology in the logistics sector and usage in the supply chain.
	[123]	Journal		✓	Encourage blockchain studies in supply chain management and define potential areas of implementation.
	[124]	Journal		✓	Review of the literature about the potentials, and trends and consider supply chain management with blockchain technology.

Table B.1 (continued) A brief summary of the literature review about blockchain technology

Field	Author	Type	General	Review	Scope
Supply chain	[125]	Journal		✓	Discussing BC entry supply chain field and increased risk and darkness points.
	[126]	Journal		✓	For future studies, it provides a direction and insight of the four barriers and categories.
	[127]	Journal		✓	Defined some cyber treatments of the blockchain system and how blockchain will react to this situation.
	[120]	Journal		✓	Created a literature review about combating of copying permissioned blockchain technology.
Energy	[119]	Journal	✓		The aim of the study that shows the contribution of blockchain to circular economy for energy management.
	[112]	Journal		✓	Bringing clarity energy consumption of bitcoin and looking beyond of these myths.

Table B.1 (continued) A brief summary of the literature review about blockchain technology

Field	Author	Type	General	Review	Scope
Energy	[117]	Journal		✓	Mentions about energy certification systems and enabling a blockchain system.
	[116]	Journal	✓		Presented idea of renewable energy management system with blockchain technology.
	[118]	Journal		✓	Prove of comprehensive work of the fundaments blockchain technology.
Agriculture	[128]	Journal		✓	Providing both technical and application surveys about blockchain technology in the agriculture field.
	[129]	Journal		✓	Examining the implementation of BC in the agricultural products with the theoretical and practical way.

Table B.1 (continued) A brief summary of the literature review about blockchain technology

Field	Author	Type	General	Review	Scope
Education	[130]	Journal		✓	Give some core knowledge about blockchain technology and its advantages for education.
	[131]	Journal		✓	Provides critical analysis of implementation blockchain technology in the higher education.
Construction	[132]	Conference		✓	A literature review was presented on how and where blockchain technology can be of use in the construction sector.
	[133]	Journal	✓		Investigating potentials of blockchain technology in the construction sector.
	[134]	Thesis	✓		Focus about construction field general problems and how problems can solve with blockchain technology.

Table B.1 (continued) A brief summary of the literature review about blockchain technology

Field	Author	Type	General	Review	Scope
Smart Grid/ Building	[135]	Journal		✓	Discussed that emerging blockchain and it contribute to how can help smart grid developing.
	[136]	Conference			Mention about security perspective of blockchain in smart cities and smart devices.
Health	[139]	Conference	✓	✓	Describe Health Chain and why Blockchain Technology should be used health sector.
	[142]			✓	Discuss the potentials of blockchain in the healthcare industry today and future applications.
	[143]	Journal		✓	Systematic review of blockchain technology applications in healthcare.

Table B.1 (continued) A brief summary of the literature review about blockchain technology

Field	Author	Type	General	Review	Scope
Health	[145]	Journal		✓	Studied important benefit of blockchain technology in the healthcare field and define fourteen implementations.
	[137]	Conference		✓	To demonstrate the potential, goals and impact of blockchain technology in healthcare.
	[140]	Journal		✓	The study about blockchain potentials and implementation areas in the health field.
	[141]	Journal		✓	Focused in implementation blockchain technology healthcare sector.
	[138]	Journal		✓	Presenting potential impact of BC in the clinical trial.
	[144]	Journal		✓	Presented using blockchain technology in the healthcare sector.

Table B.1 (continued) A brief summary of the literature review about blockchain technology

Field	Author	Type	General	Review	Scope
	[146]	Journal		✓	Highlighted potentials of blockchain technology in healthcare industry.
	[147]	Journal		✓	Provided a literature review about the important role of BC in healthcare field with Covid-19.
Law	[148]	Journal		✓	Providing a different perspective about legality in blockchain.
General definitions	[93]	Journal		✓	Giving deep information about blockchain technology, its history, consensus algorithm, smart contracts and cryptography mechanisms.
	[90]	Journal		✓	Providing general historical background, architecture, manner of work, pros and cons, and applications in different sectors.
	[88]	Journal	✓		Providing such widely trusted computer systems and cryptographic techniques.

Table B.1 (continued) A brief summary of the literature review about blockchain technology

Field	Author	Type	General	Review	Scope
General definitions	[149]	Journal	✓	✓	Aimed that fill the gap in the literature and examine such proposals for governmental issues.
	[114]			✓	Described blockchain technology beyond Bitcoin and give examples from different sectors.
	[115]	Journal		✓	Present a systematic mapping by collecting all relevant research.
	[91]	Journal		✓	Present a perspective to identify blockchain algorithm and architecture and also the security part.
	[150]	Journal	✓		Detected the aspects that need improvement in the architecture of blockchain and IoT systems.
	[151]	Journal		✓	Defining blockchain adoption and its technological development.

Table B.1 (continued) A brief summary of the literature review about blockchain technology

Field	Author	Type	General	Review	Scope
General definitions	[29]	Conference	✓		Discussing difficulties and security problems of blockchain technology in IoT.
	[152]	Journal	✓		Tried to comprehensive survey and discussing BC architecture, challenges, and opportunities
	[94]	Book	✓		Provides the fundamental principles underlying blockchain technology.
	[95]	Document	✓		Discusses terminology, trends, or future outlooks