International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Assessing the Future Impact of Blockchain Technology on Industry Operations

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Abstract: ***This research focuses on the evolving application of blockchain technology across various industries by relying on a combination of secondary data, including both qualitative and quantitative sources. The paper explores how blockchain, initially designed for Bitcoin, is now being integrated into finance, healthcare, and agriculture, among other sectors. Key blockchain features, such as decentralization, transparency, and security, are analyzed alongside the challenges like scalability, energy consumption, and lack of regulation. The paper concludes by emphasizing blockchain's potential to revolutionize industries through improved efficiency and cost reduction, despite existing limitations.***

Keywords: blockchain technology, decentralization, transparency, scalability, industry applications

1. Research Methodology

The research mainly used secondary data, both qualitative and quantitative, from academic sources. Considering the fast - growing nature of blockchain technology, my research depended on more recently written sources to deliver an accurate and relevant conclusion. All sources were extensively reviewed before being chosen, ensuring the paper's validity, as all the sources are relevant to the question.

Qualitative data was carefully and thoroughly reviewed to discover how blockchain can be implemented in various industries. To achieve this, I used a variety of sources such as academic journals, industry blogs, and in - depth studies from reputable authors and organisations. Quantitative data was used to identify blockchain trends and future projections through statistics and financial reports from market research firms. I analysed real - world case studies where blockchain has been implemented to assess its effectiveness, cost - efficiency, and impact on operational processes.

2. Introduction

Blockchain is a chain of blocks that stores information in a decentralised and distributed network. Nakamoto originally created it in 2009 as the underlying architecture for Bitcoin. Since then, blockchain has evolved, and apart from cryptocurrencies, it can now be used in financial and social services, healthcare facilities, and much more.

The features of blockchain, including decentralisation, immutability, and transparency make transactions more secure and tamper - proof. Services that people depend on in their daily lives such as transferring money, payments, voting, land and identity records all rely on intermediaries. Relying on a single intermediary to validate and authenticate transactions leaves room for manipulation and intersections of data. Blockchain disrupts this standard and records transactions transparently by distributing information across a network of nodes, eliminating the need for a central authority.

Although blockchain technology shows great potential, it comes with many setbacks. Scalability is a huge concern for blockchain, such as in Bitcoin, due to the blocks' limited size and frequency and the number of transactions the network can process. The average block creation time in Bitcoin is 10 minutes, and the block size is limited to 1 MB, which restricts the network's throughput. Increased use of blockchain would also require substantial storage space, energy, and regulation policies. Hence, several measures need to be put forward to address these issues if blockchain is to undergo large - scale adoption.

It is predicted that global spending on blockchain will reach $19 billion in 2024 as companies are harnessing blockchain technology to streamline operations and enhance traceability and transparency. This paper will explore the opportunities, benefits, and challenges of incorporating blockchain in different industries.

Understanding Blockchain Technology

A blockchain is an immutable ledger that consists of a chain of blocks, each linked to the next using cryptographic techniques. The blocks each contain a set of data and form a chronological chain of information. It uses consensus mechanism, where all nodes on the network must agree on the validity of the transaction before adding it to the blockchain.

Each block in a blockchain is comprised of three components:

1) **The Header**: The header summarises the rest of the block, containing metadata such as the previous block's hash and a timestamp recording the exact time the block was created.
2) **The Body**: The block body contains the main information, such as the list of transactions and smart contracts stored in the block.
3) **The Hash** is a unique cryptographic value that represents the entire block and is used for verification purposes.

Blockchain technology employs peer - to - peer (P2P) networks to create a distributed and secure ledger that logs transactions as immutable, time - stamped digital blocks. The following steps outline the process of a blockchain transaction:

a) **Initiation**: The transaction process begins when a user creates and signs a transaction using their private key. The transaction includes the recipient’s address, the amount being transferred, and the transaction fee.
b) **Propagation**: Once created, the transaction is broadcast to the network. Nodes on the network receive and validate it, ensuring that it adheres to the network's rules.

c) **Block Addition**: Once the block is added to the blockchain, the transaction becomes an immutable part of the ledger and is now confirmed.
d) **Confirmation**: Depending on the blockchain's design, transactions might require multiple confirmations (additional blocks added after the block containing the transaction) to be considered fully secure and irreversible to guard against potential attacks.

Understanding the characteristics that make blockchain technology so promising enable us to grasp its true potential. These include:

1) **Privacy**: Blockchains do not store personal information and use encryption methods to authenticate users undertaking transactions.
2) **Transparency**: The information on the blockchain is available to all nodes and users in the network; it is not possible to hide any information.
3) **Integrity**: This works in two ways. Firstly, data integrity: changing and falsifying blockchain blocks is virtually impossible. This is also called immutability. Secondly, user integrity: data about the transactions undertaken by a node are recorded and can be linked back to the user undertaking them.
4) **Security**: The use of blockchains requires cryptographic tools and public/private keys by all participants.
5) **Consensus**: A decision - making algorithm for the nodes on the network to reach an agreement quickly and without bias, ensuring the system's smooth functioning.
6) **Distributed trust and governance**: The blockchain bypasses the need for a trusted central authority. Instead, trust is spread across the network.
7) **Open source**: All individuals can freely access software needed to use blockchain (Zambrano et al., 2017).

Current Applications of Blockchain

Blockchain was a technology created to support the famous cryptocurrency Bitcoin. Bitcoin was released in 2009 and making it the first cryptocurrency. In 2024, there are over 46 million Bitcoin wallets holding at least $1 of value (Duarte, 2024).

According to the original Bitcoin whitepaper, the main purpose of this cryptocurrency was to create a decentralized electronic payment system between parties by eliminating central intermediaries (Valdivia et al., 2019). Bitcoin allows for increased user independence, financial inclusion, and substantial returns on investments to investors.

It is essential to understand that Bitcoin is the most successful application of blockchain but is not limited to it. Blockchain technology can be used in diverse applications, and this paper will analyse how effectively it can be integrated into several industries.

Finance

As financial institutions seek to modernize their operations and enhance the security and efficiency of transactions, blockchain has demonstrated its potential to reshape the landscape of financial services. Its main objective is to replace the existing processes by eliminating the need for "trusted third parties. " The use of blockchain technology to conduct money transfers, cross - border payments, insurance, smart contracts, and auctions has led to its exponential growth. Countries such as the USA, Australia, Canada, South Korea, and Russia have been encouraged to invest in blockchain development to provide efficient, fast, and low - cost transaction platforms (Zhang et al., 2020).

Firstly, smart contracts hold immense promise for automating and enhancing financial services. Smart contracts follow simple "if/when…then…" statements written into code on a blockchain. A network of computers executes the actions when the predetermined conditions have been met, such as releasing funds to appropriate parties. The blockchain is then updated when the transaction is complete. This reduces the processing time and administrative costs, creating a more efficient way to negotiate contracts without the need to rely on third - party registrations or heavy documentation. For example, Propy, a real estate marketplace, lets users buy and sell homes, using blockchain and smart contracts to make property transactions immutable and protect against title fraud. Therefore, smart contracts offer the world a safer, more verifiable way of creating societal agreements that involve the transfer of value and data.

Another use of blockchain in financial services is cross - border payments. Cross - border payments are transactions between different parties from various countries. Payment applications accounted for 44% of global blockchain revenue in 2022, making it one of the most prominent blockchain use cases. Usually, banking and financial institutions facilitate cross - border payments, which involves a complex network of intermediaries, such as correspondent banks. This leads to high transaction fees, longer processing periods, and an opaque payment process. By implementing blockchain technology these issues can be resolved. Blockchain transactions reduce intermediary fees and currency conversion costs, making these payments more affordable. The cryptographic nature of blockchain reduces the risk of fraud and unauthorised access, enhancing the security of transactions. Finally, smart contracts on blockchain platforms can automate payment agreements, ensuring that parties receive funds only if certain conditions are met. According to a report by Jupiter Research, implementing blockchain will enable banks to save up to $27 billion by the end of 2030 on cross - border settlements.

Finally, a third emerging use of blockchain in the financial sector is in the stock market. The existing mechanism of conducting transaction in the stock market is complicated, time - consuming, costly, and risky. Blockchain can significantly contribute to this sector in resolving most of these problems. There are numerous middlemen between stock buyers and sellers. A single trade might involve stockbrokers, depositories, banks, and clearing corporations. Through smart contacts, buyers and sellers can carry out the transaction directly, eliminating these intermediaries. Furthermore, human regulators can be biased when administering transactions, but blockchain can trace potentially suspicious transactions and can do it without human intervention (Wright & De, 2018). Finally, most investors expect regular dividends from their investments. With the traditional system, it takes several weeks to get the dividend in hand, so companies could save time and money by implementing smart contracts to create self - executing

payments to release dividends to shareholders. (Rechtman, 2017). tZERO designed a blockchain - based platform to reduce costs and settlement time while increasing transparency. This platform uses cryptographically secure distributed ledgers to make settlement processes as smooth as possible.

To conclude, the financial sector could profit significantly by integrating blockchain technology into its services. Financial institutions can benefit from blockchain technology to promote trust, transparency and cut expenses. Blockchain's cryptographic algorithms resolve security concerns as they make data almost impossible to tamper or access illegally. Although integrating this technology into finance services comes with various challenges, it is expected to be used by hundreds of financial corporations in the future.

Healthcare

With the growing fascination for blockchain and its adoption in different organizations and industries, a number of use cases have been identified for the application of blockchain in healthcare service. The global blockchain technology market in the healthcare industry is expected to cross $500 million by 2022 (Sullivan, 2019). Blockchain can be used for health record - keeping, clinical trials, patient monitoring, improving safety, displaying information and transparency. It can maintain the financial statements in hospitals and minimise the data transformation time and cost. Many countries have already started to integrate blockchain into their healthcare systems, including Estonia, UAE, Singapore, and the United States.

Firstly, blockchain can be employed in the healthcare sector to resolve the severe issue of falsified medicines. According to the Healthcare Research Grants organisation, 10% to 30% of the pharmaceuticals sold in underdeveloped nations are fake. In low - to middle - income countries, 1 in 10 drugs in market circulation is estimated to be falsified or substandard (Bagozzi & Lindmeier, 2018). Blockchain technology can provide protection from counterfeit drugs as companies can gain full transparency over their supply chain. This can be implemented by a system involving participants or "nodes" including intermediaries such as the manufacturer, distributor, retailer, and consumer. Each node can store data about specific fields. The distributor can store information about the medicine ID and the delivery time of the medicine. Each node can access data from the blockchain up to the current status of the medicine. This enables the whole journey of the medicine to be visible from any node at any time, allowing the consumer to know the genuineness of the drugs they purchase.

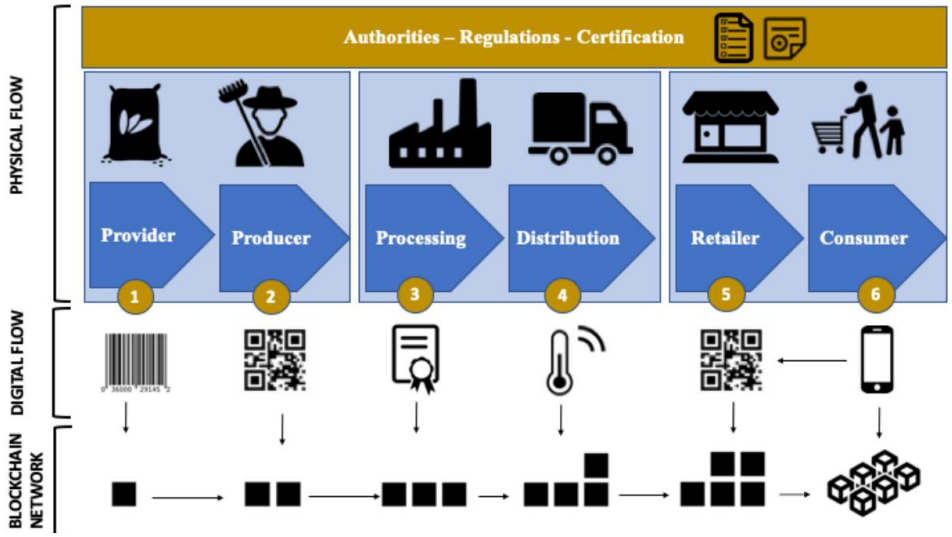
Furthermore, the security and integrity of patient information can be ensured by integrating blockchain technology into the healthcare sector. Keeping track of patient data security is among the hospital sector's top priorities. This approach for keeping track of health files lacks accessibility and confidentiality, with 725 data breaches being reported to OCR in 2023. When new healthcare data for a patient is created (e. g., from a consultation or surgery), a new block is created and distributed to all peers in the network. After most of the peers approve the new block, the system will add it to the chain. This ensures patient data remains encrypted and tamper - proof during transmission, and any unauthorised modifications can be detected. MedicalChain is a UK - based health technology platform that already allows patients to securely share their medical records with healthcare providers. Access is enabled through smart contracts, where patients set specific permissions for each healthcare professional.

Finally, blockchain is expected to impact how clinical trials are conducted. According to IBM, 70 % of healthcare leaders predict that blockchain's greatest impact within healthcare will be the improvement of clinical trial management and the sharing of electronic health records (EHR) (Tkachenko & Tkachenko, 2020). Clinical trials are conducted to evaluate the effectiveness of therapies to treat or provide a partial remedy to particular diseases. Scientists need to record data on test outcomes, patient records, and other variables. Data collected during clinical trials should be authenticated so that scientists, pharmaceutical firms, and policymakers are confident in the quality of results. Blockchain technology can help to eliminate the falsification of data and the under - reporting or exclusion of undesirable results of clinical research. The Estonian government developed a blockchain system for validating patients' IDs in collaboration with Guardtime, a digital security company with Dutch roots. Each resident receives a digital wallet that connects their EHR information to their ledger identification (Angraal et al., 2017). It uses blockchain to secure and streamline clinical trial records.

To conclude, blockchain has the potential to be utilised extensively by the healthcare sector in fields such as health insurance, the pharmaceutical industry, EHR, biomedical and health research, drug quality control, and medical lectures (Radanović & Likić, 2018). Overall, this technology can significantly enhance and revolutionise how patients and physicians treat and use clinical records, improving healthcare services.

Agriculture and Food

The food supply chain refers to the process that food goes through, including all the stages of production, storage, packaging, transporting, distributing, selling, and consuming products (Ststrace, 2023). Agriculture and food supply chains are interlinked since agricultural products are almost always used as inputs in some food supply chains, where the consumer is usually the final client (Maslova, 2017). The current food supply system is inefficient and unreliable. It is estimated that the operating costs of supply chains make up two - thirds of the final cost of goods. Another issue that arises is that when people buy products locally, they aren't aware of the origins of these goods or their environmental footprint. Blockchain provides solutions to the shortcomings of the current food supply system, and examples of implementation of the technology in the food industry will be discussed below.



Firstly, blockchain could improve the traceability of food in terms of safety and transparency. The food traceability market was predicted to be worth $14 billion by 2019 (MarketsandMarkets Research, 2016). Blockchain makes it possible to track the journey of food items from the farm to the consumer. Each participant in the food supply chain could record information about their products on a blockchain ledger, as shown in Figure 2. Every action that takes place along the food chain is recorded in the blockchain (bottom layer of Figure 2) and then must be accepted by all participating parties. This information could include the origin of the product, its production methods, and its transport and storage conditions. The information is immutable, ensuring the data's integrity, improving food quality, reducing waste, and increasing consumer trust. Walmart is working with IBM and Tsinghua University of Beijing to create blockchain - based supply chain applications in China, specifically focusing on the pork market (Higgins, 2017). They reported that the time taken to track food reduced from days to minutes. The European grocer Carrefour has used blockchain to trace food origins in various categories, such as meat, fish, fruits, vegetables, and dairy products (Carrefour, 2021).

Blockchain can also be used to increase food security, which the Food and Agriculture Organization (FAO) defines as when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (World Food Summit, 1996). Recently, this has proven to be difficult due to humanitarian crises such as environmental disasters and political and ethnic conflicts. Blockchain can be used to transparently deliver international aid by disintermediating the process of delivery and responding more rapidly and efficiently to humanitarian emergencies (AID Tech, 2017). Digital food coupons were distributed to Palestinian refugees in Jordan's Azraq camp via an Ethereum - based blockchain, which helped over 100, 000 refugees.

Finally, blockchain can facilitate insurance programs that secure farmers' incomes. Weather extremes threaten agricultural production, risking food security (Lesk et al., 2016). Agricultural insurance schemes are a common tool used to manage these weather - related risks. Farmers pay an insurance premium before their cropping cycle begins and receive an insurance payout whenever they experience a loss on their farm caused by weather extremes. The insurer bears all the insured risk, and farmers are able to recover quickly from losses and continue their operations. ARBOL is an InsurTech platform that allows farmers to receive payments for droughts, floods, or other weather conditions that negatively affect their crops. It offers smart contracts to smallholder farmers in Cambodia as larger insurers would not find covering them profitable.

To conclude, blockchain has many benefits in the food industry, including improving transparency in food systems, enhancing food flows, reducing food waste, helping deter food fraud, and offering new tools for increasing trust in food. It can potentially reduce food waste while reducing operational costs and improving efficiency in agrifood supply chains (Li et al., 2021). Dubai uses blockchain through its "Food Watch" initiative, a technology platform that digitalizes food safety processes and provides nutritional information on all edible items served through the 20, 000 or more food establishments (Detwiler, n. d.). The global blockchain market for the food supply chain was estimated at $128.87 million in 2020 and is expected to reach $886.18 million by 2025 (ReportLinker, 2024).

3. Challenges and Limitations

Despite blockchain's great potential, it faces numerous challenges that limit its wide usage. These include both practical and ethical issues, which will be discussed in detail in this section. The limitations of the use of blockchain technology in Bitcoin will be used as examples in this section to show how these shortcomings have impacted its most popular field, to assess how significantly it could impact others.

a) Data Security

Data security poses a significant challenge in blockchain technology due to the transparency and immutability of the data recorded on the ledgers. Once a transaction is included in the blockchain, it is permanent and cannot be changed or removed. All participants in the network have access to any

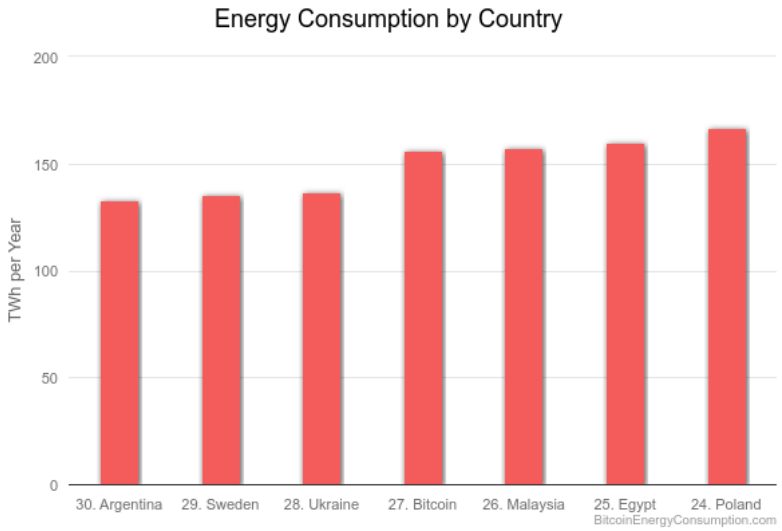
personal or sensitive information stored on the blockchain, raising serious privacy issues. The risk of data breaches and unauthorised use of personal information hinders the widespread adoption of this technology. Some cyber - attacks blockchain could be vulnerable to include stealing, spy attempts, and Denial - of - Service (DoS) attacks. One of the stealing attacks was against MtGox, a bitcoin exchange based in Tokyo in 2014 that resulted in a loss of $600 million (Porru et al., 2017).

b) Scalability

More than 13, 000 transactions occur with Bitcoin daily (Chauhan et al., 2018). This number of transactions is making Bitcoin transactions bulky as every node needs to store and validate every transaction. To validate these transactions on the blockchain, each node must store all of them and check if the source of the current transaction has been spent. However, due to the original limitations on block size and the time it takes to generate a new block, the Bitcoin blockchain can only handle approximately seven transactions per second. This falls short of meeting the real - time processing needs of millions of transactions.

c) Energy Consumption

While performing transactions, miner computers consume a lot of electrical energy (O'Dwyer & Malone, 2014). The mining process attracts individuals to run power - hungry devices to secure a solid revenue stream. This has caused the total energy consumption rate of the Bitcoin network to reach a new high in recent years. According to a report published by the International Energy Agency, the overall consumption of the Bitcoin network is higher than in many countries (Vranken, 2017). If Bitcoin were a country, it would rank as shown in Fig.2 below.



Bitcoin is responsible for consuming a massive amount of energy and contributes to an extreme carbon footprint. China's coal - fired power plants are fuelling the Bitcoin network. Nature Climate Change (October 2018) even suggested that Bitcoin mining alone could push global warming above 2 ◦C within less than three decades.

d) Integration and Interoperability

Blockchain lacks common standards that would allow different networks to connect. There is an absence of consistency among blockchain protocols, making mass adoption difficult at the moment. Integrating blockchain solutions with existing applications, such as legacy applications, can be challenging. These outdated systems may not be ready to be smoothly integrated with newer systems and applications that include blockchain solutions. Different vendors may have developed old and new applications using different architectures, environments, and programming languages. They will have to redesign their old systems entirely if they wish to embrace blockchain.

e) Regulations

The legal system is still struggling when it comes to technology and technical disputes. Rules, laws, and specific regulations are needed to address such issues directly. Without regulations, it is challenging for some industries to use blockchain. For example, a manufacturer agrees with a supplier on material purchases and documents it using a smart contract approved by both parties. An issue may be if the order was not delivered within the agreed time or required specifications. This issue may need to be solved with the support of the legal system. However, this becomes a problem since the legal system may not accept the smart contract as a binding agreement. Many governments have threatened or even made cryptocurrencies illegal in their territories because of these issues. Bitcoin is banned in countries such as Pakistan, Iran, Ecuador, Morocco, and more. Fig.3 shows the global legality of bitcoin.

These are just a few of the issues that need to be further researched and analysed to create more effective industrial applications that reap the full benefits of blockchain. Future work in this field can address and resolve these issues for more efficient, scalable, and secure blockchain industrial applications.

4. Conclusion

Blockchain technology is emerging as a fast - growing technology worldwide, with many firms and countries trying to find ways to exploit its advantages. A recent survey concluded that 2019 was a turning point for blockchain when a radical shift happened in the attitudes of business leaders who recognized that blockchain can serve as a pragmatic solution to business problems across industries (Deloitte, 2019). Its characteristics like transparency, immutability, and decentralisation have attracted almost every business. A range of industries are starting to adopt or consider adopting blockchain to facilitate their operations to streamline processes, enhance security, increase efficiency, and ultimately reduce operation costs. As a result, applications in the financial, energy, agriculture, healthcare, and manufacturing domains are emerging.

North America has dominated the blockchain market so far. Its blockchain technology market size was valued at $5.25 Billion in 2022. The growing presence of major players, such as IBM Corporation, Microsoft Corporation, and Oracle Corporation will likely help to realise this growth. Europe currently holds the second position in the market as countries like France, Germany, Italy, Spain, Luxembourg, and the Netherlands are heavily investing in digital currencies. Asia is expected to record the highest growth during the period as manufacturing companies in China, Japan, Oceania, South Korea, and Southeast Asia are increasing their technology investments.

Despite blockchains' undeniable potential to transform several industries, widespread adoption of the technology faces many obstacles. These include scalability, privacy leakage, regulations, selfish mining, energy consumption, and interoperability. In my opinion, the largest setback of integrating blockchain technology into these industries will be standardization. Companies use various blockchain platforms and solutions, each with its own protocol, code language, consensus process, and privacy safeguards. This lack of interoperability may harm the growth of the blockchain industry, as there is no standard protocol for blockchain networks to integrate and collaborate with each other. However, this can be resolved by introducing industry - wide standards between the systems and the introduced blockchain applications. There are many standardizing efforts in progress for blockchain technologies, including IEEE Standards Associations, the International Organization for Standardization (ISO), and Standards Australia ("Standards Australia, " 2017). Developing these standards will aid in the seamless integration and enhanced utilization of blockchain technology.

Therefore, the question is no longer whether blockchain is here to stay but how quickly the technology will reach mass adoption. Simplifying outdated processes, reducing bureaucracy, allowing transparency, and increasing trust levels for industrial processes are the motivations for growing blockchain's penetration into the business world and among governments.

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