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A review of the key challenges of non-fungible tokens

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ABSTRACT

The nonfungible token (NFT) marketplace spiked in the recent past. The concept originated initially as a token standard of Ethereum, an open-source blockchain with smart contract functionality, where each token is characterized by distinguishable signs. These types of tokens have unique digital properties that allow their distinct identification. NFTs, with their distinct qualities, can be fluidly traded with customized values according to their ages, rarity, and liquidity. The trading of NFTs has heavily influenced the growth of the decentralized application (dApp) marketplace, as exponential returns (thousand folds from their original value) on its ever-expanding market are being observed, leading to worldwide attention. However, the NFT ecosystem is in its nascence, and the associated technologies are still in their infancy. New researchers might be fascinated with the exponential, yet nebulous evolution of NFTs; however, this novelty has contributed to the paucity of systematic and conclusive published research work on this topic. This review portrays the NFT ecosystem multidimensionally, wherein the paper commences with an overview of state-of-the-art NFT technology and furnishes summary standards and desired properties. Finally, the study concludes with an elaborate discussion of the future outlook for and prime challenges faced by NFTs.

1. Introduction

The recent developments in the digital era have not only changed the way of doing business, but have also featured disruptive changes and innovation in the businesses themselves. Being independent of the development level of economies, the digital era allows a wide range of entrepreneurs to initiate new business models (Ali et al., 2021; Racat et al., 2021). To survive in this competitive environment, firms need to apply new strategies, engage new models and utilize new technologies to be part of the innovation lifecycle (Kajikawa et al., 2022). Failing to keep up with this new phenomenon can lead to missed opportunities. In addition to the massive growth in business areas relating to information collection, management, and storage, investments in information have also recently shifted to a new phase through digitalization (Ali et al., 2020a; Sahut et al., 2022). Blockchain technology has played an essential role in this structural change (Jaradat et al., 2022). The utilization of blockchain for digital asset management in various business segments has gained recognition. These assets carry value and are tradable in an entirely different marketplace from their conventional counterparts. Nonfungible tokens (NFTs) are an excellent example of this evolution. Thanks to NFTs, a completely new market for data-based digital assets has been created.

Nonfungible tokens demonstrate ownership of a digital item in the same way that people own crypto-assets (Dowling, 2022; Jones, 2021). This digital item may be a text, image, sound file, or video, which may correspond to a physical good or can be purely digital, such as an in-game item (Jones, 2021; Thilagaraj and Davis, 2021). The main transactional categories are games, collectibles, and digital arts (Jain et al., 2022). In simple terms, NFTs are the baseball cards of the digital age; one might seek to collect NFTs from his or her favourite player's collection, such as Lionel Messi's exclusive set of three licenced NFT collectibles in the blockchain platform Ethernity (Boardroom, 2021; Ali

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et al., 2022), but with far greater exchangeability and potential due to their convenience of proving the possession of digital art or collectibles (Mani, 2021). Unlike cryptocurrencies where each unit is presumably identical and worth the same, each NFT is always unique. Even though NFTs have been around since 2014, the NFT boom only began in 2021. The immense popularity of the Bored Ape Yacht Club NFTs that has become one of the recent public face of NFTs (CENT, 2022). The value of these unique monkey faces had once peaked to over US$ 400,000, however recent US interest rate hikes and the fall of the third largest cryptocurrency exchange marketplace FTX that sank the crypto market in 2022 has brought down NFT prices and the cheapest NFTs are now trading for 65 ETH (around US$78,000). The use of these NFTs as a status symbol and the value it generates is extraordinary. The value of an NFT is based on what a buyer is willing to pay for it, which may involve significant amounts if a famous artist makes the NFT and the buyer is a collector who can afford to pay large amounts of money (Chen, 2018). An NFT auction may work in a similar way to an online auction on platforms such as eBay. Each work may be displayed online as an image file that contains data about the work's title and who owns it.

When novel technologies such as NFTs emerge, a transformational shift occurs, as they change the way businesses operate. These shifts have been witnessed and well documented with technologies such as robotics (Wirtz et al., 2018), artificial intelligence (Paschen et al., 2020), and virtual reality (Farshid et al., 2018). These shifts have congruently caused a revolution in segments such as marketing (Huang and Rust, 2021); for instance, in support of their launch of the unisex A$AP NAST x Reebok Zig Kinetica II Edge shoes, rebook and A$AP launched Limited-Edition NFTs on RFOX's NFT Platform (Redfox Labs Limited, 2021). Much of the shift in the NFT parlance has been focused on its technical and regulatory dimensions (Sankar et al., 2017; Arcenegui et al., 2021) in addition to altering the way brands are marketed to engender consumer interest and subsequent buying behaviours (Sankar et al., 2017). NFT applications and their implications not only affect technological and regulatory norms but are also poised to revolutionize the marketing of the future. It is worth mentioning - the 'glow in the dark' NFTs created by chef Sperxos to market his exclusive real-world dining experience (OpenSea, 2021). Research has evinced that NFTs can improvise marketing campaigns, and their linkage to blockchain shall facilitate the way business is conducted in the future (Steve and Kominers, 2022).

Since NFTs run on a blockchain without a central authority, transactions can happen quickly and seamlessly across political borders with no procedural overhead. All the transactions connected to the NFTs are recorded on a blockchain in a tamper-proof and auditable manner, so one can easily keep track of the exchange record of the property that the NFT represents. This property also expedites the arbitration processes of many transactions (Ante, 2021). For instance, during follow-up sales, one could show the provenance of a piece of art going back to the creator. NFTs may potentially disrupt online shopping, which is a continuously evolving industry. NFTs as technology may help streamline digital sales while enabling lifetime product data tracking in a way that was not previously possible, as users can have access to every data point across the product's lifespan, empowering a more transparent e-commerce ecosystem. For example, one of the most recent platforms atma.io, where connected cloud products are sold, runs on Hedera and is used to monitor the carbon emissions of unique products. The technology has the potential to enable e-commerce platforms to track products from their inception to their disposal or recycling into a different product. This facility can replace the traditional method of SKU and barcode tracking with a blockchain-based analogue that can store each product as a distinct digital print and thus allow the identification of each product in the whole value chain. As a result, it encourages transparency in addition to facilitating a commensurate and equitable profit-sharing process among various stakeholders in the value chain.

Scholars and industrialists are showing increasing interest in NFTs. The significance of retail merchandise is evident from the fact that 1.3 % of the cryptocurrency market was captured by the liquidity of NFT-based projects as of 2021 Q1. Moreover, remarkable progress has recently been witnessed in the actual usage of NFTs. The NFT sales were initially anticipated to reach USD 12 million in 2020; however, sales actually reached USD 340 million, significantly surpassing this estimation (Cointelegraph Research, 2021). While Q2 2021 cryptocurrency markets have shown some slowdown along with NFT sales, the active market wallets are expected to rise in the long run. These numbers indicate the revolutionary development of NFTs, leading them to be declared the prospective digital asset class of the near future. Some of the essential operative NFT-based projects include crypto-punks, crypto-kitties, NBA top shots, 3DPunks, Hashmasks, Polkamon, unofficial punks, NFT boxes, and Chubbies (Ezhilchelvan, 2011; Mani, 2021).

With a whopping global market-size estimate of US$ 200 billion, NFTs are understood to be the bases to unlock the market for collectibles (Fenech, 2018). Experiments in the past have delved into tokenizing software licences in a spectrum of verticals; some are luxury goods and cars (Butcher, 2018), such as art cars in Dubai, which offer a new class of vehicle investment through auctioning and selling limited edition art cars with NFTs (Artcar, 2021). Similarly, the accounting firm EY released a press note stating that they use this technology to facilitate private equity transactions (Khatri, 2018). With these diverse adoption cases, innovation is being encouraged on the Ethereum blockchain, wherein efforts are being made to enable Ethereum to process a higher number of transactions using state channels (McGinn et al., 2016).

Technically, NFTs can be interpreted as fingerprints that thrive on a blockchain and strengthen the benefits of the technology (Honest, 2021; Badar et al., 2020). This qualifies NFTs to be utilized for a spectrum of applications, including medical records and their identity verification (Wilson et al., 2021), intellectual property (Dolganin, 2021; Okonkwo, 2021), real estate, academic credentials (Wang, 2022), gaming industry (Francisco et al., 2022), supply chain and ticketing (Binns, 2022) applications. Illustratively, NFTs also allow artists to demonstrate their artwork with the click of a few buttons, allowing them to reduce their typically colossal public-demonstration budgets, which can then flow to other areas, such as art production costs, consumption by end-user, and retrading of the art through the blockchain (Russell, 2022). Technologies such as these enable professionals engaged in producing intangible products to convert their labour into revenue with a few clicks and save on time and costs.

Moreover, NFTs also serve as alternatives to conventional assets, wherein they are recognized as financial instruments of the digital era (Wang, 2022; Yarovaya et al., 2022), enabling individuals and corporations to invest and reap gains. The massive market growth and rapid development in channelling digitizable items make them a bourgeoning asset class among all orthodox alternatives (Wang, 2022; Wang et al., 2022). Thus, it is plausible to predict that this group of instruments may soon become ubiquitous, with their existence becoming more prevalent in academic circles and in the lives of common people.

NFTs have immense potential to influence decentralized market spaces and provide future business opportunities; however, they are in their early lifecycle stages (McGinn et al., 2016; Sankar et al., 2017; Butcher, 2018). Contextual to blockchain-enabled technology, most of the product markets are decentralized, owing to two principles. First, there is the absence of a nodal agency that may ensure adherence to prescribed norms in addition to regulating the whole process; and second, this vacuum has led to the encouragement of direct transactions between buyers and sellers, which colossally influences the development of decentralized marketspaces and thus unregulated market spaces that could lead to immense business opportunities. However, the lack of research and scientific data on the application of NFTs has been a major challenge inhibiting the development of systematic knowledge in this area (Jaradat et al., 2022). Systematic efforts need to be made by the research and practitioner community to carefully address these potent challenges. Although there has been some literature that is accessible to the general public, such as that published in open forum posts, a systematic investigation of this parlance and its implications is missing.

This manuscript aims to underscore the gaps that hinder the progress of NFT development and attempts to present a panorama of its potential future progression. The paper aims to first review the current body of knowledge and provide a detailed background surrounding the science of NFTs, including their standard and targeted properties. Second, the review dissects the open challenges in NFT ecosystems; for example, blockchain-based NFT systems still face the chronic challenge of privacy and data inaccessibility. Thus, the paper aims to investigate the following research question: *What are the key challenges faced by NFTs?*

The rest of this review is organized as follows. Section 2 provides the NFT background, followed by a summary of NFT standards and properties in Section 3. Section 4 provides an overview of the detailed methodology that was adopted for this review. Section 5 discusses the open challenges of NFTs in detail. Section 6 outlines the implications of our study and future research directions. Finally, Section 7 presents the conclusion of this work.

2. NFT background

Blockchain is often described as a digital ledger that records various types of transactions carried out on a network by different parties in a continuous manner (Hughes et al., 2019; Li et al., 2018). A public blockchain operates without a central authority. The entities securing the network are called nodes, which form the infrastructure of a blockchain (Yaga et al., 2019). Nodes are connected through a pre-agreed consensus mechanism, and they exchange the up-to-date blockchain data while keeping a copy of the ledger, thereby preserving and disseminating the blockchain data. For this reason, a blockchain can be said to exist on nodes (Beck et al., 2018). The Bitcoin network in particular runs on tens of thousands of nodes, a number that increases in the long run. Each transaction, such as the exchange or transfer of digital assets such as ownership, rights, and liabilities, is recorded on the blockchain (Ali et al., 2021). The fundamental component of the blockchain is a block containing a record of each valid transaction conducted on the blockchain (Glaser, 2017). Public blockchains such as the Bitcoin network allow open access to and participation of the public without the need to reveal their identity (Xu et al., 2016; Sankar et al., 2017). Conversely, private blockchains are only accessible to users approved by a central authority such that the authority knows the identity of each user (Guo and Liang, 2016). Regarding blockchain usage in general, Janssen et al. (2020) studied the challenges and issues that organizations encounter when adopting blockchain technology, and they proposed a holistic conceptual framework for blockchain adoption.

While Ethereum is a blockchain that is essentially developed based on Bitcoin, it has the ability to run smart contracts as a distinguishing factor (Ali et al., 2021). Ethereum is also a public permissionless platform that still made use of a proof-of-work consensus algorithm as of early 2021, similar to Bitcoin, for securing the network and is in the stage of being transitioned to the more energy-efficient proof-of-stake consensus mechanism. Similar to Bitcoin, Ethereum also uses Byzantine fault tolerance to overcome the challenges associated with coin mining and disagreements between network components (Vogelsteller and Buterin, 2015). The development of the Ethereum Virtual Machine (EVM) has made it possible to decentralize the execution of smart contracts, exploring further use cases other than those only involving the transfer of assets (Watanabe et al., 2016). Hence, other blockchain-based assets, such as Ethereum tokens, may be developed on the Ethereum network, where tokens represent the digital assets existing on Ethereum, which can also be regarded as Ethereum sub-currencies (Yermack, 2017). Ethereum has opened the prospect of developing various decentralized applications through the integration of smart contracts and tokens, as described in (Ølnes et al., 2017). Recalling that the definition of smart contracts proposed by Szabo (1996) described a smart contracts as a self-executing electronic transaction protocol, the idea has been realized through Ethereum and has been quite revolutionary in the financial world. Indeed, decentralized applications (dApps) may fall into different categories, such as voting systems, intellectual property (IP), finance, decentralized finance, and games (in particular, trading or collection-based games). While the types of dApps are not limited to the aforementioned, domain name registries and particular software for company governance can also utilize Ethereum as a back-end system. dApps can be designed assuming an anonymous network as well as a reputation-based network, where node operators keep a record of trusted nodes.

The development of decentralized applications offers users the ability to enforce ownership rules, state transition functions, and transaction formats according to their will (Jennath et al., 2019). Ethereum code development has become widely accessible, as it may be written in any of the multiple high-level programming languages available today (Vogelsteller and Buterin, 2015). Hence, through smart contracts, parties can undergo transactions with each other in an environment without any security threat even in the absence of a regulatory third-party authority. This paves the way for the development of other applications based on the concept of smart contracts. The Ethereum Improvement Proposals (EIP)-721 introduced the NFT concept, which was later considered in the standard EIP-1155 (Radomski et al., 2018). Digital technologies have transitioned the way contents are structured, used, saved, shared, consumed, and interfaced. NFTs go a step further and advance the digitalization of assets or chains of ownership for physical and intangible assets while harnessing them as transparent, encrypted, and concrete forms of resources (Dowling, 2022; Popescu, 2021). One of the most interesting features of NFT is its ability to collaborate with another NFT, thereby creating a new entity that can be technically attributed to the feature of extensibility. This characteristic feature explores the possibilities that funnel into NFT-enabled digital assets (Kugler, 2021). One such popular example of these features is the Crypto-Kitties, a blockchain-based game, and The Sandbox shop (Kanellopoulos et al., 2021).

The intrinsic features of NFTs are not the same as those of typical cryptocurrencies such as Bitcoin (Shirole et al., 2020). While Bitcoin has been described as a network in which each unit is essentially identical and exchangeable, NFTs are unique so that one NFT cannot be replaced with another NFT of the same kind; therefore, they are noninterchangeable or to be exact, they are nonfungible. Hence, because each NFT is unique, NFTs can be used for identification purposes. EVM involves the use of gas as a fee to perform computations and transactions such as the exchange of NFTs by users. The main purpose of gas is to restrict undue and overuse of the network, thus preventing inefficiency. Users can spend Ether (Ethereum currency) by buying the required amount of gas to run their code on EVM. NFTs representing ownership can be applied to many areas, including supply chains. There are also critical studies such as that undertaken by Tönnissen and Teuteberg (2020) that discuss the impact of blockchain for this context with an explanatory model and argue that blockchain may not lead to the removal of intermediaries in supply chains. In this case, it is more likely that a new central intermediary will control the rules, and the number of actors may increase in supply chains.

Regarding further technicalities, decentralized applications can be developed more easily with the help of smart contract interface standards. The well-known Ethereum token standard, which offers holders assorted access or governance rights and facilitates initial coin offerings (ICOs) for fundraising, is the ERC20, which specifies a standardized interface for fungibles tokens and has been widely used as an innovative form of crowdsourcing (Rohr and Wright, 2018; Kong and Lin, 2021). The fungible tokens can be subdivided and easily transferred and managed through ERC20. On the other hand, the newly approved ERC 721 standard supports NFTs and has paved the way for various novel applications (Chirtoaca et al., 2020). These ERC721-supported NFTs are different from crypto-currencies and ERC20 tokens in that the former are nonfungible while the latter are fungible. Another iconic standard is the ERC721, which specifies every NFT with an internationally allocated unique ID that is transferable and can include metadata as an option

(Vogelsteller and Buterin, 2015; Entriken et al., 2018).

The ERC721 gives a detailed account of the preconditions and postconditions that explain how to build unique tokens on the blockchain. However, no details pertaining to the execution of this standard exist. It is up to the developer to decide on the implementation of this standard. This standard does not mandate rules for token metadata or restrict adding supplemental functions (Pirker et al., 2021). Therefore, the development of a smart contract application based on this standard is needed, such applications will record the digital ownership that exists on the blockchain, and a trusted entity can endorse the application for greater credibility. However, the basic version of the ERC721 interface standard is not adequate for the execution of contracts associated with NFTs. Rather, certain NFT use cases demand some features that are not offered by the standard ERC721 and must be created and arranged; such features include the following options: token creation, token deletion, contract access control, and others. Some libraries offer a basic implementation model of the ERC721 standard. However, these basic models and platforms do not suggest solutions to the concerned challenges. Hence, basic smart contracts are likely to be configured only to some extent due to a lack of advanced features and versions of the standard (Chirtoaca et al., 2020).

Similar to other developing technologies, NFT applications also face numerous challenges in their developmental phase. Usually, the challenges associated with areas of usability (Valdeolmillos et al., 2019), management (Johnson, 2020), privacy and security concerns (Gervais et al., 2016), and extensibility (Zamyatin et al., 2021) are faced by NFT applications. Being regarded as a technology that is in its early stages, both the system and human-related factors were involved in the emerging challenges; the system-related challenges were mostly due to issues in blockchain-based platforms, while the human-related challenges included issues associated with management, rules, and the public (Wang et al., 2021).

3. NFT standards and properties

This section provides a detailed account of the main NFT standards and key NFT properties that govern the development and use of NFTs.

3.1. Token standards

This section elucidates token standards related to NFTs, including ERC-20 (Fabian and Vitalik, 2015), ERC-721 (William et al., 2018), and ERC-1155 (Witek et al., 2018). These standards have an immense bearing on the continuing NFT schemes.

3.1.1. ERC-20 & ERC-721

One of the most predominant token standards comes from ERC-20 (Fabian and Vitalik, 2015). It explains the idea of fungible tokens that can be dispensed on top of Ethereum once the requirements have been satisfied. The standard replicates tokens (in terms of both type and value). Herein, each token is indiscriminate and similar to all the others. This stimulates the hype regarding the ICOs from 2015 to the present. Public chains and diverse blockchain-based applications can still have performance limitations for the effective utilization of smart contracts due to operational security and maintenance issues. This challenge can be overcome by the introduction of decentralized apps or dApps in short (Raval, 2016; Cai et al., 2018) that are completely hosted by a P2P blockchain system that can be fully automated as a decentralized autonomous organization (DAO). Since dApps supported by ERC-20 are open source and decentralized with no central point of failure and internal support, it is gaining much attraction for seed funding by investors. Juxtaposing this is the ERC-721 (William et al., 2018), which hosts a nonfungible token standard that varies from the fungible token. This standard is unique and distinct from the rest. Specifically, each NFT has a uint256 variable called a token ID, and each contract address and uint256 token ID pair is universally unique. Moreover, the token ID can be expanded as input to engender distinct credentials such as images of zombies or cartoon characters (William et al., 2018).

3.1.2. ERC-1155

This standard ERC-1155 (Multi Token Standard) (Witek et al., 2018) involves both fungible and nonfungible tokens and offers an interface that can represent countless tokens. In the previous standards, each token ID in a contract comprises a single type of token; for example, ERC-20 ensures that each token type is positioned in a distinct contract. Similarly, ERC-721 installs a group of nonfungible tokens in a single contract with identical configurations. However, ERC-1155 involves a range of token ID functionality, wherein each of them solitarily signifies a different configurable token type (Witek et al., 2018). This arena may contain exclusive information, such as metadata, date, supply, lock-time, or any other attribute.

3.2. Key properties of NFTs

NFT schemes fundamentally distribute applications (Buterin, 2015) and thus carry the properties of their substratum public ledgers. The current manuscript summarizes the key NFT properties in detail. *Verifiability* refers to the token metadata and nature of ownership of the NFT, which can be publicly corroborated (Wang and Kogan, 2018). *Transparent execution* represents the NFT activities minting, selling, and purchasing, which are publicly accessible. *Availability* refers to NFT systems being workable as required when required during any period, i.e., availability of all the tokens and issued NFTs for selling and buying. *Tamper resistance* refers to the quality of NFT metadata and the ability of its trading records to be persistently stored and not manipulated once the transactions are confirmed. *Usability* is the NFT attribute wherein every NFT includes updated ownership information that is user-friendly and clear (Valdeolmillos et al., 2019). *Atomicity* refers to the ability of an NFT transaction to be accomplished in a single ACID (atomic, consistent, isolated, and durable) transaction. The NFTs can be executed and run in the same shared state. Finally, *tradability* is the ability of every NFT and its corresponding product to be arbitrarily exchanged and thus formally traded (Wang and Kogan, 2018).

4. Research methodology

The works of Watson (2015) and Ali et al. (2018) are referred to as the guidelines for this current review method. The review is sequenced via a specific protocol and process that is initiated to identify, select and assess the literature based on the parameter of relevance. The article aims to make the review process highly efficient (Tranfield et al., 2003), replicable, objective, candid, unbiased, and rigorous (Boell and Cecez-Kecmanovic, 2015). Derived from the works of Kitchenham and Charters (2007) and Ali et al. (2018, 2020b), the review is sequenced as a three-stage process including the stages of planning, execution, and reporting. Next, the three processes are explained.

4.1. Planning stage

This phase characterizes the identification of the requirements of the review. Although studies on key challenges to the use of NFTs exist, the academic literature pertaining to the topic and its review has been underdeveloped. Thus, the paper will contribute to the literature by providing a detailed analysis of the existing knowledge in research and practice. Second, at the planning stage, the following research question was identified: *What are the key challenges faced by NFTs?* Thus, the review aims to answer this research question in particular for future generations of researchers to appreciate the challenges of NFTs for future research and the adoption of NFTs.

Third, the criterion for the selection of articles was set using specific strategies and techniques. Herein, an integrated search strategy was embraced to include a search engine – automated search – on different

electronic databases and the inclusion of a manual review of assorted publications (Golder et al., 2014). For the current review, the chosen online databases include the ACM digital library, Scopus, Web of Science, Emerald, IEEE, and Science Direct. Moreover, strategic filtering of tools was used to limit and mine the requisite research results for each of the chosen databases (McLean and Antony, 2014). The broad manual review was conducted by reading through the title and abstract of each research article (Golder et al., 2014), followed by systematic reading of the assorted content of these selected articles to exclude extraneous articles (Ali et al., 2018).

The fourth step entails developing the research review protocol, which served as a foundation to interpret the current theoretical and practical perspectives of the theme. This review followed the initial classification framework proposed by Ngai and Wat (2002). The study encapsulates the proposed cataloguing framework, which contains seven diverse types related to some distinct aspects of the prime challenges related to the use of NFTs. These types include usability challenges, privacy issues, governance considerations, security issues, extensibility issues, environmental impact, and intellectual property concerns; additionally, the subcategories within each of the components of the framework are included (see Table 2).

4.2. Execution stage

At this stage, the strategies of the planning phase were extended to filter the articles to obtain those of relevance to this review paper. The main methods applied in this review study were 1) identifying the search terms and words as an ever-evolving process, which began with using unique technical terms recognized in the area (Hu and Bai, 2014). This study identified the following keywords: (“challenge” OR “issue” OR “barrier” OR “obstacle” OR “consideration”) AND (“NFT” OR “blockchain”); 2) database filtering tools were used to enhance the relevance of the search results; features of temporal restriction were used, wherein the research period was restricted to the period from 2014 to 2021 (Zhang et al., 2014); 3) subsequently, the results were manually checked with a focus on the title and abstract to ensure their relevance (Pucher et al., 2013); 4) the filtered articles from the previous step were thoroughly analysed (reading full-text article) to determine whether they contain relevant knowledge, information, theory and the like in the research area (Shea et al., 2007); 5) finally, to ensure that all the filtered articles obtained as a result of the above systematic steps were relevant to this area of study, a quality assessment criterion was applied (Hu and Bai, 2014). For the quality evaluation, we used some quality evaluation criteria to ensure that all of the papers in our review met the minimum quality level (Hu and Bai, 2014). To determine if an article should be included, a checklist was created. The checklist questions were adapted from Ali et al. (2018, 2021) and Sadoughi et al. (2020). The following criteria were utilized:

- The discussion of the research objectives was satisfactory.
- The research questions and research problem were clear.
- The data used were well described and available.
- The adopted methodology was well presented and used.
- The research results were well presented and were designed to answer the research questions.

Elaborate details regarding the study selection process, and the results of each stage of the process are listed in Table 1.

4.3. Summarizing stage

The current review was conducted between January 24th, 2022, and April 23rd, 2022 by observing the protocols presented in the planning stage. The initial search yielded a total of 317 articles. Finally, only 42 articles remained after filtering through the review stages, quality assessment criteria, proposed framework, and categorization framework, as presented below (Table 2).

Table 1
Selection process and results.

Study selection process and result		
Stage	Strategies	Result
Stage 1: Search based on the keywords	Identifying search keywords: • Challenges or issues • NFT • Blockchain	317
Stage 2: Database filtering tools applied	Apply database filters: • Language • Year of publication • Area of study	198
Stage 3: Exclude articles based on title and abstract	Reading of the title and abstract	127
Stage 4: Exclude articles based on full-text scanning	Reading of the full articles	86
Stage 5: Exclude articles based on the quality assessment	Quality evaluation: • The research objectives • The research questions • The research problem • The data used • The adopted methodology • The research results	42
Total articles		42

The categorization framework is based on the context-mechanism-outcome perspective (Watson, 2015), presented in earlier discussions and supported by the grouping of subcategories from various studies. These were relevant to the key challenges in using NFTs, and specifically to the challenges regarding privacy issues, governance consideration, security issues, extensibility (scalability) issues, environmental impact, and intellectual property issues that emerged from the review process. Next, the key challenges faced by NFTs are discussed in detail.

5. Discussion of NFT key challenges

NFTs are increasingly being used across different verticals because of their unique implications that match well with secure internet-driven transaction methods. However, the wider acceptance of NFTs will depend on how some of the inherent challenges of the technology are addressed. In this part of the paper, the common challenges are explained along with how these challenges threaten to inhibit the acceptance of this technology.

The development of NFT applications could be materialized by overcoming a trail of barriers, which is common to most technologies in their infancy. The review represents some key challenges from the perspectives of usability, security, governance, and extensibility, engulfing both the system-level issues offered by blockchain-based platforms and man-based factors such as governance, regulation, and society (Fig. 1).

5.1. Usability challenges

The term ‘usability’ refers to the measure that maps users’ effectiveness, efficiency, and satisfaction when analyzing a specific product/design. When the interfaces of NFT transacting platforms becomes more user-friendly, the adoption of NFTs will become more mainstream. As most of the NFT schemes are built on top of Ethereum, its drawbacks will be embedded into the NFTs. The review portrays two major challenges that directly impact user experience.

5.1.1. Slow confirmation

Impregnable security has been a unique characteristic of NFT

Table 2
Categorization framework.

Domain	Category	Sub-Category	Description	Sources
NFTs Challenges	Usability Challenges	Slow confirmation	NFT procedures are typically conducted by sending transactions via the smart contract for reliable and transparent management.	Valdeolmillos et al. (2019); Wang et al. (2020a); Wang et al. (2019); Gudgeon et al. (2020); Bano et al. (2019).
		High gas prices	It is one of the main problems for NFTs, especially when minting the NFTs at a large scale that requires uploading the metadata to the blockchain network.	Wang et al. (2021)
	Privacy Issues	NFT data inaccessibility	The inaccessibility of data compounds the practicality of its use and limits the full potential of data reuse.	Uribe and Waters (2020); Wang et al. (2021); Dev et al. (2022); Benson (2021).
		Anonymity/ Privacy	NFT transactions are reported to rely on underlying Ethereum platforms, which offer pseudoanonymity.	Uribe and Waters (2020); Wang et al. (2020b); Wang and Kogan (2018); Noether (2015); Raman et al. (2018); Bolton and Cora (2021); Das et al. (2021)
	Governance Consideration	Legal pitfalls	NFTs are at present not subject to governmental regulation, which implies that there is little or no legal protection for those who create, sell, buy or invest in them.	Johnson (2020); Fairfield (2021)
		Taxable property issues	IP-related products are slotted as taxable property under the current regulatory framework.	Wang et al. (2021)
	Security Issues	Spoofing	The term is attributed to the capability to impersonate another entity (person or computer) on the system, which resembles authenticity.	Wang et al. (2021); Blackshear et al. (2021); Chohan (2021); Sharma et al. (2022)
		Tampering	The malicious alteration of NFT data that disrupts its integrity.	Garay et al. (2015); Garay et al. (2017); Blackshear et al. (2021); Chohan (2021).
		Repudiation	The situation where the author of a statement cannot decline, which pertains to the security property of no reputability.	Menezes et al. (2018); Blackshear et al. (2021); Chohan (2021).
		Information disclosure	A situation in which information is uncovered by unauthorized users, which violates privacy.	Menezes et al. (2018); Li et al. (2019); Li et al. (2020); Blackshear et al. (2021); Chohan (2021).
	Extensibility Issues	NFT interoperability	NFT systems are isolated from each other; thus, once users select a product, they can only sell/buy/trade them within the same ecosystem/network.	Zamyatin et al. (2021); Garnett and Neuburger (2021).
		Updatable NFTs	Transitional blockchains apprise their protocols using soft forks (minor modifications that are compatible forwards) and hard forks (significant modifications that may conflict with previous protocols).	Wang et al. (2021); Ciampi et al. (2020).
	Environmental Impact	Sustainability	The ability to maintain or support a process over time. It is often broken into the following three core concepts: economic, environmental, and social. Many businesses and governments have committed to sustainable goals, such as reducing their environmental footprints and conserving resources.	Chen et al. (2020); Rehman et al. (2021); Kiayias et al. (2016); Mora et al. (2018); Hastings et al. (2018); Jiang et al. (2021); The New York Times (2021); Rehman et al. (2021); Shrimali and Patel (2021).
	Intellectual Property Issues	Intellectual property rights	Any rights associated with intangible assets owned by a person or company and protected against use without consent. Intangible assets refer to nonphysical property, including the right of ownership in intellectual property.	Purtill (2021); Rehman et al. (2021); Wood (2014); Okonkwo (2019); Purtill (2021); Okonkwo (2019); Bamakan et al. (2021).

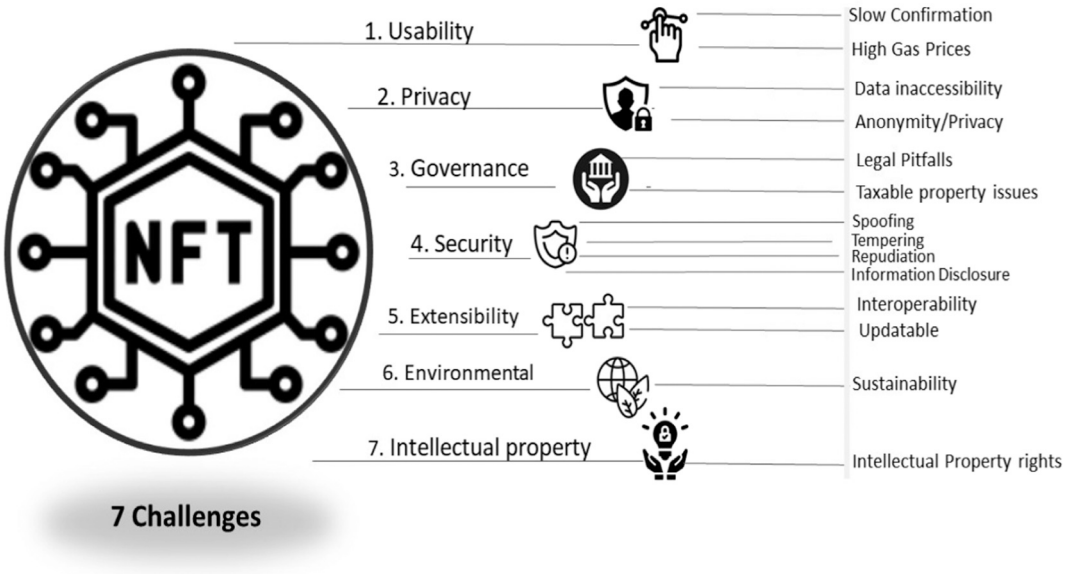

Fig. 1. Key challenges faced by NFTs (Adopted from Table 2)

transactions in general. To keep transactions secure, the technology follows a strong verification and authentication protocol. This is likely to adversely impact the speed of NFT transactions. NFT-related procedures typically warrant sending transactions through smart contracts to ensure reliable and transparent management. However, the current NFT systems are carefully entwined with their embedded blockchain platforms, which retards their performance, viz. Bitcoin reaches merely 7 TPS (Valdeolmillos et al., 2019), while Ethereum reaches only 30 TPS. These nuances lead to exceptionally sluggish confirmations of NFTs. This challenge could be controlled by redesigning blockchain systems (Wang et al., 2020a), optimizing their structures (Wang et al., 2019; Gudgeon et al., 2020), or upgrading the consensus mechanisms (Bano et al., 2019). Prevailing blockchain systems fail to accomplish such necessities.

5.1.2. High gas prices

With growing concerns related to the carbon footprint of blockchain-related technologies, there is concern that ledgering NFT transactions may lead to higher energy consumption. This has become a rampant problem for NFT marketplaces, especially when minting and ledgering at a larger scale that mandates uploading the metadata to the blockchain network (Wang et al., 2021). Every NFT-related transaction is costlier than a typical transfer transaction, owing to the computational resources and storage processing needs of smart contracts. At the time of writing, the cost of mining of NFTs is over US$ 60. Furthermore, the completion of a simple NFT trade can cost between US$ 60 and US$100 per transaction. This is a major impediment, wherein exuberant fees, an outcome of complex operations and high rates of congestion, greatly inhibit its amplified adoption. Platforms that intend to make NFTs more popular must take steps to allay fears of higher energy consumption and transition to more sustainable and energy-efficient platforms such as those powered by Ether. Moreover, the continued pursuit of more energy-efficient systems will lead to NFTs not being viewed as gas guzzlers.

5.2. Privacy issues

Research has shown that user privacy epitomes the adoption of any system (Uribe and Waters, 2020). Moreover, the data (stored off-chain but related to on-chain tags) lead to the challenge of losing linkage and misuse for malice; further discussion shall underscore the details of privacy issues as follows.

5.2.1. NFT data inaccessibility

Owing to its genesis from blockchain, conventionally, NFT projects (Wang et al., 2021) use a cryptographic "*hash*" as the identifier instead of a copy of the file, which is tagged with the specific token and then logged onto the blockchain to save on gas consumption. This leads to a loss of user confidence in the NFT because the original file is prone to loss and damage. Several NFT projects combine their systems with specialized file storage, such as IPFS, that permits users to discover a piece of content as long as someone on the IPFS network is hosting it somewhere. Obviously, such systems have issues; for example, in cases when the users "*upload*" NFT metadata to IPFS nodes, there is no guarantee that their specific data will be simulated among all the nodes. Furthermore, the data may eliminate the option of accessibility if the asset is stored on IPFS and the single node storing it becomes disconnected from the network (Benson, 2021). Another major problem is that an NFT may point to an erroneous file address in instances in which the user fails to prove that s/he owns the NFT. Simply, an external system as the core storage component is unreliable for an NFT system, which makes it vulnerable to flaws.

5.2.2. Anonymity/privacy

This dimension of NFTs requires detailed investigation. Most NFT transactions are reported to rely on underlying Ethereum platforms, which offer pseudoanonymity rather than stringent anonymity (Uribe and Waters, 2020). Partial confidentiality could be maintained by users if the links between their real identities and corresponding addresses are kept confidential; otherwise, all the user activities under the specific address are observable. The prevailing privacy-preserving solution tools such as homomorphic encryption (Wang et al., 2020b), zero-knowledge proof (Wang and Kogan, 2018), ring signature (Noether, 2015), and multiparty computation (Raman et al., 2018) are not yet able to be used with NFT-related schemes owing to their complex cryptographic primitives and security conventions. Analogous to other types of blockchain-based systems, reducing inflated computation costs is vital to the implementation of privacy-promised schemes (Bolton and Cora, 2021).

5.3. Governance consideration – Lack of regulations

Similar to most cryptocurrencies, NFTs, on the one hand, enjoy strict scrutiny from the government and, on the other hand, lack proper regulation within the corresponding market. This review portrays the following two common governance considerations.

5.3.1. Legal pitfalls

Relative to blockchain and its other derivatives, at the global level, NFTs are at present not subject to governmental regulation, which implies that there is little or no legal protection for those who create, sell, buy or invest in them. NFTs provoke regulatory and policy concerns across widespread areas (Johnson, 2020; Fairfield, 2021). Impending concerns include commodities, cross-border transactions, customer data, etc. It is important to understand this regulatory scrutiny before elaborating on NFT deliberations. Countries such as India and China have strict legislative laws for cryptocurrencies and for the sales of NFTs. Furthermore, Dubai issued the virtual assets law to regulate these assets in Dubai in an attempt to become the regional and global destination for all digital transactions. Governance and its intervention is pivotal to exchanging, trading, selling, or buying NFTs. According to regulatory sanctions, users can only trade derivates on authorized exchanges, such as established stocks and commodities, or exchange tokens person-to-person. However, France is more munificent, with its deliberations to implement laws that are more congenial to regulate the service of digital assets. In other countries, existing laws are being modified to make them suitable for handling such issues. In some countries, buyers are required to follow complex and even contradictory terms, which act as a deterrent and thus mandate diligent participation of all parties involved.

5.3.2. Taxable property issues

IP-related products are slotted as taxable property under the current regulatory framework (Wang et al., 2021), although NFT-based sales are an exception to this. Barring a few countries, such as the U.S., tax cryptocurrencies are considered property. Most countries worldwide have yet to affirm this in this manner. This lack of recognition may positively influence financial crimes, with NFT trading as the alibi. With specific taxable regimes, the government would be encouraged to make the sale of NFTs legitimate. Governments can regulate individual participants with tax liability on any capital gains from NFT properties, which can encourage wider recognition. Additionally, NFT-for-NFT, NFT-for-IP, and Eth-for-NFT exchanges should be taxed. Tax regimes with commensurate tax brackets can catalyse the evolution of NFTs. NFT-related trades should be preceded by deliberations, intervention, and advice from professional tax departments.

5.4. Security issues

An NFT system is an assembly technology with a blend of blockchain, storage, and web applications (Blackshear et al., 2021). The system is vulnerable to the properties of each component; thus, vulnerability of one component may make the whole system vulnerable to attackers (Chohan, 2021). While smart contracts generated for NFTs are capable of ensuring that the creator of a certain NFT (perhaps a digital art piece) can receive royalties each time it is sold or purchased, such payments

may not be reflected automatically if the transactions are not always conducted through the exact same platform. In addition to this risk, the other potential security issues are elaborated below.

5.4.1. Spoofing

Spoofing is the ability to impersonate another entity (person or computer) on the system, which resembles authenticity. When a user interfaces to mint or sell NFTs, a malicious attacker may steal their authentication credentials and exploit embedded vulnerabilities or pilfer the user's private key (authentication) to tender beneficial transfer of ownership of NFTs illegally. Thus, the current review recommends the need for formal verification of NFT smart contracts and the use of cold wallets to curtail private-key leakage.

5.4.2. Tampering

Tampering involves the malicious alteration of NFT data that disrupts its integrity. Illustratively, blockchain is a full-bodied public transaction (Garay et al., 2015; Garay et al., 2017), and a hash algorithm produces preimage resistance and second preimage resistance (Garay et al., 2017). Ideally, the metadata and ownership of NFTs cannot be maliciously manipulated after the transaction is confirmed. However, the share of data that is saved outsides the blockchain can be mutilated; thus, tampering may occur at the principal ownership of the NFT. Thus, the review herein recommends that users share both the hash data and original data with NFT buyers when trading/exchanging NFT-related properties so that incidents of tampering can be averted.

5.4.3. Repudiation

Repudiation refers to the situation where the author of a statement cannot decline (Wang et al., 2021), which pertains to the security property of no reputability (Menezes et al., 2018). Precisely, when a user sends an NFT to another user, it cannot be denied. This is ensured by the blockchain security and unforgeability property of a signature scheme. Although the hash data can be corrupted by the attacker, it can bind with the attacker's address. Thus, to avert such mishaps, the review recommends the usage of multiple signatures contracts, which can partly resolve the issue since each binding action must be established by multiple participants.

5.4.4. Information disclosure

Information disclosure is an outcome of an event in which information is uncovered by unauthorized users, which violates privacy (Menezes et al., 2018). In the NFT system, the state information and the instruction code are entirely transparent via instruction codes and any state and its changes are publicly accessible, by any observer. The moment a user enters the NFT hash into the blockchain, a malicious attacker(s) can materialize the linkability of the hash and the embedded transaction. Thus, it is herein recommended that NFT developers include privacy-preserving smart contracts (Li et al., 2019; Li et al., 2020) in place of plain smart contracts to ensure user privacy, thereby protecting the whole NFT system.

5.5. Extensibility issues

This aspect is dual-fold, wherein the first aspect emphasizes whether the system is powerful enough to interact with other ecosystems, and the other involves the ability of an NFT system to replenish itself with updates when the current version becomes redundant (Wang et al., 2021).

5.5.1. NFT interoperability

NFT systems are isolated from each other; thus, once users select a product, they can only sell/buy/trade that product within the same ecosystem/network. This seclusion is an outcome of the underlying blockchain platform. Interoperability and cross-chain communication are generally impediments to the inclusive adoption of dApps. Thus, based on the works of Zamyatin et al. (2021), it can be inferred that cross-chain communications can only be realized with the aid of a reliable external ecosystem. Although the property of decentralization can be lost in this manner, many NFT-related projects adopt Ethereum as their foundational platform (Garnett and Neuburger, 2021). This indicates that they share similar data structures and thus facilitate the sharing of data under the same regulations.

5.5.2. Updatable NFTs

Transitional blockchains apprise their protocols through soft forks (minor modifications that are compatible forwards) and hard forks (significant modifications that may conflict with previous protocols). Ciampi et al. (2020) present a formal discussion, wherein they highlight the trade-offs of applying blockchain updates to the existing protocols. Despite using the generic model, the new update still enjoys stringent mandates, such as tolerating specific adversarial behaviours and being consistently available online, during an updating process. These NFT schemes are dependent on their foundational platforms and exist asynchronous to them (Wang et al., 2021). While the data are stored as distinct components, the most important logic and token ID are nevertheless chronicled on-chain. Thus, a systematic updating of the system with consistent revisions is a prerequisite.

5.6. Environmental impacts

Progressive knowledge of NFTs and their parent technologies is encouraging people to invest in crypto-technology, although there have been significant studies that report its damaging effects on the natural environment. Even though some of the current blockchains address environmental impact considerations, such as Polygon and Hedera, which are committed to becoming carbon neutral, the first generation of blockchains remains environmentally harmful. For instance, Ethereum, which is the foundation of NFT technology, is projected to utilize 44.94 terawatt-hours of electricity annually, which approximately corresponds to the power consumption of developing countries such as Qatar and Hungary (Rehman et al., 2021). This is one of the core sustainability issues faced by NFT technology. Therefore, to overcome this specific challenge, NFT transaction platforms must continue to pursue more energy-efficient ways of hosting and validating data.

5.6.1. Sustainability

Fundamental to the progression of NFTs is the challenge of environmental sustainability of the embedded proof-of-work process of blockchain mining, which is shown to consume colossal amounts of energy in the requisite corroboration processes (Chen et al., 2020). The Cambridge Bitcoin Electricity Consumption Index (2021) reports that such proof-of-work mining used to verify Bitcoin devours more electricity than the cumulative consumption of countries including Finland, Kazakhstan, Chile, Belgium, and Austria (The New York Times, 2021). Another distinct study identifies that the entire amount of electricity used for the mining of bitcoins is commensurable to the electricity used by countries such as Malaysia and Sweden (Rehman et al., 2021). Another startling study reports that the adoption of blockchain-embedded technologies can spike the Earth's temperature by 2 °C, which is unprecedented. Crypto-miners have been alleged to have caused power shortages in Iran; congruently, a recent study showed that the energy consumption from blockchain-based technology in China exceeds the total greenhouse emissions from the Czech Republic and Qatar annually (Jiang et al., 2021).

This evidence confirms that high energy consumption and the associated environment are obvious challenges for the progression of NFTs. French digital artist Joanie Lemercier is reported to have cancelled the NFT production of his artwork and its sale, after computing that the processes will consume the same amount of electricity in 10 s that his studio was estimated to have used for two years (Barber, 2021). Nevertheless, the steady progress in this area and the mounting use of novel proof-of-stake next-generation verification consensus models

necessitate drastically reduced power to prove its reliability and thus markedly condense the overall power consumption of the process (Kiayias et al., 2016; Hastings et al., 2018). The proof-of-stake process swaps miners with validators who own greater amounts of cryptocurrency assets and thus has a correspondingly superior impact on transaction validation. Such entities pursue rewards by offering their tokens as securities to authenticate the validation process (Shrimali and Patel, 2021).

5.7. Intellectual property issues

Intellectual property issues are yet another well-documented, significant concern regarding NFT risks and hindrances (Purtill, 2021). The current review asserts that intellectual property rights are one of the key challenges.

5.7.1. Intellectual property rights

One of the significant processes is to evaluate the ownership rights of individuals to certain NFTs (Purtill, 2021). Determining whether the seller genuinely possesses and owns the NFT before making a purchase is critical to the whole transaction. There have been reported instances in which NFTs of photographs or reproductions have been minted (Rehman et al., 2021). Inferentially, upon the purchase of an NFT, the owner receives the rights to utilize the asset but not the rights to its intellectual property. The metadata of the embedded smart contract clearly state the terms and conditions of owning an NFT (Wood, 2014; Purtill, 2021). This is indicative of the fact that NFT applications may offer immense revenue-generation opportunities (Okonkwo, 2019), although they face copious challenges. Although NFTs are being endorsed by luminaries and there is colossal market hype surrounding them (Purtill, 2021), there have been challenges that need to be addressed. The trading volume of NFTs surged more than once in just one year, indicating that they have great potential. The trade of NFTs, on the other hand, is not uniformly governed by any specific regulations (Okonkwo, 2019; Bamakan et al., 2021). Regulatory interventions to ensure the protection of intellectual property rights will play a significant role in creating confidence in users who transact on NFT platforms. Lack of trust in whether their intellectual property rights are secured may lead to reluctance and slower adoption of this technology, regardless of the benefits that it may offer.

6. Research implications and future directions

6.1. Research implications

Since NFTs are relatively recent technology manifestations, there is a lack of research literature on the topic, especially from the academic research point of view. This comprehensive review will bridge that gap by providing a holistic summary of present and prospective challenges and opportunities. This review will help researchers and practitioners predict, pre-empt and mitigate the potential risks that threaten to inhibit the wider adoption of NFTs. Since this review has identified the ongoing challenges faced by NFTs, two important research implications of this review can be drawn. First, at an institutional and economic level, *NFTs for decentralization and commons economic management* are an important research topic in this context. Second, at an individual level and with marketing and consumer psychology perspectives, *NFTs for consumer behaviour on digital ownership* can be a significant research implication. A discussion of these two research implications of this review study is discussed next.

6.1.1. NFTs for decentralization and commons economic management

The NFTs are a part of the Web3 movement, where the World Wide Web is based on blockchain technology. Even though Web 2.0 brought massive innovation in digital technologies and its penetration into business and society, there is an over centralization of technology capabilities and data ownership with a few "*Big Tech*" companies, viz. Alphabet, Apple, Meta, Amazon, and Microsoft. While there is some research demonstrating that the Web3 movement can support NFTs by improving data security, scalability, and privacy (Potts and Rennie, 2019) and that markets are betting on NFTs as part of the future of the internet, there are also sceptics that consider NFTs to be just another technology buzzword. It is important to recognize that the underpinning blockchain technology for NFTs can support the decentralization of the internet (Zarrin et al., 2021). However, there is also evidence of the consolidation of key players, particularly in the cryptocurrency area, such as the domination of blockchain APIs by Alchemy and Infura and the control of blockchain marketplaces by a few companies, for example, OpenSea. These types of consolidation for profiteering are the very nature of the free markets in capitalist economies. We believe that research into the areas of ongoing challenges and evolution of NFTs is important to advocate for commons-based economic management (Frischmann, 2005). NFTs and blockchain technology have moved rapidly beyond the current socioeconomic environments. The economic view of the commons promotes the value of shared assets against private ownership (Ostrom, 1990) and this concept has been extended to knowledge commons (Ramakrishnan et al., 2021) and digital commons (Ramakrishnan et al., 2022) in the IT discipline. Beyond the economics and IT disciplines, the commons approach is developing in the areas of intellectual property and other scientific research. However, the commons perspectives on deregulation, democratization, and decentralization of assets are largely theoretical in the economics discipline (Karpoff, 2022), and this perspective has only started to pick up in the digital landscape. Therefore, it will take some time for NFTs in the digital space to become mainstream economic tools because society and world economies and markets still need to do a great deal of catching up to ensure wider adoption in the cyber world. It is a timely call for researchers in the FinTech area to address the challenges highlighted in this review from the areas of finance and IT capabilities as socioeconomic conditions evolve.

6.1.2. NFTs for consumer behaviour regarding digital ownership

The advent of the always online and immersive environment of the metaverse has opened up the possibilities of extending the joy of personal ownership of real-world objects to the virtual world. This is a fascinating development that is driving consumer behaviour towards digital ownership of NFTs. There is a sense of pride and human pleasure in technology consumption when it is complemented by digital ownership (Kirk et al., 2015). The exponential growth of cloud computing has enabled businesses and government agencies to deliver services while not needing to own a technology infrastructure since technology access is provided as a service model (Ali et al., 2020b). This behaviour has extended to consumers with the use of on-demand services, such as streaming music and movies. However, there is an abundance of research that suggests that consumers seek to own digital technologies despite their intangible nature (Kirk and Swain, 2018). The "licence" model of selling digital rights, e.g., giving rights to stream media on personal devices, yields customer satisfaction because the selling of the rights has been problematic, for instance, copyright issues. However, NFTs present a platform for consumers to showcase digital artefacts with the record of sale and ownership. This is the primary driver for the exponential growth of NFTs. Since NFTs provide a certification of authenticity for digital objects, consumers are attracted to NFTs due to the token it provides to assure customers of the uniqueness of their possession in addition to the sense of ownership and value generated from obtaining something perceived to be very rare. One of the examples is selling digital versions of Andy Warhol's drawings as a token in the NFT marketplace – this is extraordinary given such sales are banned in the physical auction market; thus, the possession NFT creations is a unique consumer behaviour dimension. This review on the challenges faced by NFTs can direct researchers and marketers to consider the pain points of NFTs and how to best address them to develop more positive

consumer behaviours regarding digital ownership. Industry leaders and content creators who would like to harness the opportunities provided by NFTs can benefit from the key insights that are summarized in this review.

6.2. Future directions

NFTs, which are an offshoot of blockchains, are becoming more mainstream, and there will certainly be much interest from researchers and industry practitioners. This paper lays the foundation for more in-depth research on NFTs in general and the potential obstacles that NFTs are likely to confront. Future researchers who choose to add to the body of knowledge pertaining to NFTs can also study in greater detail the promising aspects of NFTs and the benefits that they promise to bring to digitalization. Each of the challenges described in this paper (the privacy issues, governance consideration, security issues, extensibility/scalability issues, environmental impacts, and intellectual property issues that emerged from the review process) can be studied separately to provide more detail regarding their specificity and uniqueness. Such a detailed approach may bring to light richer insights and possible solutions in the management, economic, legal, and social levels that go beyond technological updates.

Future researchers may also consider studying the impact of each of these challenges and how these challenges evolved historically. Looking at the promising prospects of wide-scale adoption of the technology that is fuelling NFTs, it is certain that this technology manifestation will attract enormous interest and traction in the future.

6.3. Research limitations

The findings of this review should be evaluated considering its limitations. First, the review focused solely on articles published in peer-reviewed journals accessible from the selected scholarly databases. Thus, broader forms of publications, such as conference papers and book chapters, were excluded. This can be a significant limitation when reviewing the erratic technology area of NFTs that is based on ever-changing blockchain platforms and their application in turbulent markets. Many innovative practices and knowledge reside in the practice and contemporary applications of NFTs that may not be captured in this review. Second, the review specifically examined the challenges faced by NFTs and used this perspective to discuss the present state-of-the-art technology. Other perspectives through which to consider NFTs, for example, using an innovation lens, digital transformation or ownership view, knowledge management discipline, or legal dimensions, were considered but not included in this review. Likewise, the review considered NFTs as an umbrella term and did not consider similar related terms, such as blockchain, specific digital asset, or unique digital identifier, as keywords. These limitations may be addressed in future research by considering additional keywords, other databases, and grey literature to expand the scope of the review.

7. Conclusion

The NFT is an emerging technology prevailing in the blockchain market. Since NFTs are recent technology manifestations, there is a lack of research literature on the topic. Therefore, this review paper fills the gaps in the literature by providing a holistic summary of present and prospective challenges. This review explores the state of the art technology related to NFTs, which may reshape the market for digital/virtual assets in the future. In addition, the study outlines existing research challenges that must be solved before achieving mass-market penetration. Contemporary challenges of using NFTs were discussed in the areas of privacy issues, governance considerations, security issues, extensibility (scalability) issues, environmental impacts, and intellectual property issues. Based on the findings, two important research implications were identified. First, at an institutional and economic level, *NFTs for decentralization and commons economic management,* and second, at an individual level with marketing and consumer psychology perspectives, *NFTs for consumer behaviour regarding digital ownership.* This review delivers a timely analysis and summary of existing NFT scenarios that will help newcomers keep up with the current progress.

CRediT authorship contribution statement

Omar Ali: Conceptualization, Methodology, Investigation, Formal analysis, Data Curation, Visualization, Validation, Writing- Original draft preparation.

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Ronnie Das: Writing- Reviewing and Editing.

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Declaration of competing interest

There are no conflicts of interest for this manuscript.

Data availability

No data was used for the research described in the article.

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