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"NFT Marketplaces design impact: comprehensive analysis of NFT market and ecosystem"

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ABSTRACT

In the last years, non-fungible tokens (NFT) have gained tremendous popularity worldwide. This technology is a unique digital identifier that cannot be copied, substituted, or subdivided, that is recorded in a blockchain, and that is used to certify ownership and authenticity. These characteristics, with transparency and scarcity brought impressive sales in exchange of cryptocurrency, which are used to purchase the digital works. Many firms are investing billions of dollars in these technologies, but many of them have gone bankrupt lately, demonstrating their high volatility and risk. There are various applications of NFTs, and many marketplaces have raised and interpreted their own way to buy and sell these digital items.

The objective of this thesis is to describe the environment that is creating around NFTs and more specifically a comparison between the various NFT marketplaces in order to forecast their direction of development and indicate the new trends that are appearing. What are the future directions of development in the NFT marketplaces? What will be the key to success in the NFT ecosystem?

In order to reach the purpose of this study and answer the research questions, a qualitative approach was deemed appropriate for this study to understand the main trends in the market of NFTs. The methodology involves a comprehensive census of NFT marketplaces, including the analysis of specific variables on their business models and technical specifications. It has been chosen to analyze the most popular marketplaces in the world, presenting a high number of volume sales and active traders. The sample has been collected from DappRadar.com with other sources, and the result is a database of 100 NFT marketplaces, on which a descriptive analysis has been made, integrated with semi-structured interviews.

The results show that the market is dominated by a few players, OpenSea above all, which has set the main trends during the last years. Regarding the applications, it has been possible to identify a few groups of platforms, distinguished by their purpose and industry. Concerning the technical specifications, many blockchains and standards have been introduced but Ethereum is the most popular network supported. However, the entrance of new players is radically changing the market.

The in-depth empirical analysis and the technical study make this research unique, which, however, still presents some limitations: the platforms that belong to cryptocurrency exchanges are not included in the database, so future research could integrate them with other platforms that are entering the market in the future.

Key Words

Non-fungible tokens, marketplace, blockchain

ESTRATTO

Negli ultimi anni, i non-fungible token (NFT) hanno acquisito una grande popolarità nel mondo. Questa tecnologia è un identificatore digitale unico che non può venire copiato, sostituito, o suddiviso, che viene registrato in una blockchain che viene usata per certificare la proprietà e l'autenticità. Queste caratteristiche, insieme alla trasparenza e alla rarità, hanno portato vendite impressionanti negli scambi con criptovalute, le quali sono usate per acquistare gli NFT. Tante aziende hanno investito milioni di dollari in queste tecnologie, ma molte sono finite in bancarotta, dimostrando un alto rischio e volatilità dell'asset. Ci sono varie applicazioni degli NFT e molti marketplace sono cresciuti e hanno interpretato i metodi con cui comprare e vendere gli oggetti digitali. L'obiettivo di questa tesi è di descrivere l'ecosistema che si sta creando intorno agli NFT e più precisamente un confronto tra i vari marketplace NFT al fine di prevedere i loro sviluppi ed evidenziare le nuove tendenze che stanno comparendo.

Quali sono le direzioni di sviluppo dei marketplace NFT? Quali saranno le chiavi per il successo nell'ecosistema NFT?

Per raggiungere lo scopo di questa tesi e rispondere alle domande di ricerca, un approccio qualitativo è stato considerato appropriato per questo studio per capire le principali tendenze nel mercato degli NFT. La metodologia comprende un censimento comprensivo dei marketplace NFT, includendo l'analisi di specifiche variabili nei loro modelli di business assieme a specifiche tecniche. È stato deciso di analizzare i marketplace più popolari nel mondo, che presentano un alto numero di volume di vendite e di utenti attivi. Il campione è stato raccolto da DappRadar.com assieme ad altre fonti, e il risultato è un database di 100 piattaforme, sulle quali è stata eseguita un'analisi descrittiva, integrata con interviste semi strutturate.

I risultati mostrano che il mercato è dominato da pochi attori, OpenSea sopra tutti, che ha impostato le principali tendenze negli ultimi anni. Riguardo le applicazioni, è stato possibile individuare alcuni gruppi di piattaforme, distinti dall'obiettivo e l'industria. Per quanto concerne le specifiche tecniche, sono state introdotte molte blockchain e protocolli ma Ethereum rimane la rete più supportata. Tuttavia, l'entrata di nuovi attori sta cambiando radicalmente il mercato. L'analisi empirica approfondita e lo studio tecnico rendono questa ricerca unica, la quale, però, presenta dei limiti: le piattaforme

che appartengono agli scambi di criptovalute non sono state include nel database; quindi, ricerche future potrebbero integrarle assieme ad altre piattaforme che parteciperanno a questo mercato.

Parole chiave

NFT, marketplace, blockchain

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Executive summary

Challenges and objective of this analysis

Non-fungible tokens represent a technology that have gained a strong attention in the last years. This technology represents a unique digital identifier that cannot be copied, substituted, or subdivided, that is recorded in a blockchain which is used to certify ownership and authenticity. These characteristics, with transparency and scarcity led people to associate to it any type of file, such as images and videos, to sell online for cryptocurrency.

The first NFT has been minted in 2014 but public attention towards NFT has exploded only in 2021. The news about the digital works being sold for record sales of billions of dollars has instigated the curiosity of the people and led many scientists to study this phenomenon. Marketplaces raised in 2017, when important collections of NFT like CryptoPunks were released, and the market remained steady until 2021, when it saw a grow of 150 times more than it was eight months earlier. However, in May 2022 the NFT market was collapsing with to the so-called "crypto winter", which led many platforms to bankrupt.

Because of these events, we are living a period of radical changes in the market of NFTs, where at first sight, now it seems that NFTs' hype has fallen, but the hype cycle model testimonies that we are still in an early phase of the life of this technology, and they may acquire new functionalities.

Research on NFTs is still limited, and focuses mostly on technical aspects, but only a few deals with their marketplaces, which are interpreting their own way to allow artists to create and sell their digital content and collectors to buy them. Collections can be widely different, from sets of in-game objects to selection of art pieces.

This study aims to investigate possible directives for the development of NFT platforms and the browsing of NFT, through the analysis of the scenario of NFT marketplaces. In particular, a complete census of NFT marketplaces has been done, analyzing specific

variables related to the main gaps that emerged from a literature review, related to both technical and business aspects.

This research has provided an empirical analysis on NFT marketplaces and has identified business and technical models common to successful platforms. This has allowed for the identification of trends and directions of development of this technology, with substantial consequences for both entrepreneurs and enthusiasts.

Literature review

In the first part of this thesis, a review of the literature has been conducted. In particular, an historical background has been presented, to describe the main events that characterized the story of technology and the major projects that have been released.

Subsequently, the main properties and characteristics of NFTs have been listed, among which the most important are verifiability, transparency, availability, scarcity, tamper-resistance, usability, atomicity, and non-interoperability.

Following this, a technical analysis of this technology has been brought, with the description of the main components used to construct NFTs: the blockchain network, the smart contract, the address, the transaction and the data encoding. Afterwards it has been presented an analysis of the blockchains, with a comparison between the various standard protocol and consensus mechanisms used by the various blockchain networks. Then there is an illustration of the main characteristics that differentiate each blockchain. The differences between on-chain transactions and off-chain transactions and their implications are clarified, and finally the advantages and disadvantages of the most important blockchain networks have been described.

After the blockchains, the NFT marketplaces have been examined. The main components of the platforms have been discussed, with various real cases investigated further: the wallets, the purchase methods and the transaction costs (including the gas fee paid to the blockchain in order to mint an NFT, the commission fee owed to the platform and the royalty fee, a percentage of the secondary sales that goes to the

original creators). Subsequently, an in-depth analysis has been made regarding the governance of the platforms, which could be centralized or DAO, implemented through proprietary token that can have different utilities, among which the governance token allows their owners to participate in the vote for the future policies of the platform.

As a result of the literature review, the main gaps found in the scientific literature regarding blockchain and NFT marketplaces have been outlined.

It emerged a lack of framework of NFT marketplaces models. In addition, there are no studies that define which incentives each platform provides to the collectors and the main benefits they bring to the creators and sellers.

Regarding the technical aspects of NFT marketplaces and blockchains, many papers describe in-depth the technical functioning of its underlying algorithms, but no research has emerged that outlines the most common technical choices, such as the blockchain supported, the consensus mechanism adopted, and the governance established.

Methodology

The research objective and the research questions have been presented and the methods used for data collecting and variable classification are all discussed in the methodology chapter. Moreover, all the variables of the database have been defined and described extensively.

The variables introduced in the database have been chosen with the aim of addressing the main research gaps found in the literature. In particular, several variables have been introduced concerning the business models of NFT marketplaces and the incentives that they can offer. Some variables have also been introduced to study which technical elements NFT marketplaces have most commonly chosen to implement, with particular attention to the blockchains supported and the type of platform offered by new marketplaces.

The extraction of data on NFT marketplaces has been made in collaboration with the Blockchain and Distributed Ledger Observatory of Politecnico di Milano, which has also

provided the main sources from which collecting the data. Then, the main interviews to some ambassadors of important marketplaces have been reported.

The methodology for the empirical analysis itself has then been described, outlining the justification for the numerous investigations and incorporating the thought processes behind the outlier numbers.

Thus, this analysis aims to *describe the current ecosystem of NFT marketplaces.*

Starting from the objective of the research and the main gaps identified in the literature, the research questions that have been defined are the following:

What are the future directions of development in the NFT marketplaces? What will be the key to success in the NFT ecosystem?

Empirical analysis

The empirical analysis is divided in three main sections: the first part presents an overview of the main NFT marketplaces in the world during the last years. The analysis has then focused on business aspects, in particular investigating the main sectors in which platform operate, and the fees applied to the transactions; in the last section the analysis has addressed the technical aspect of the marketplaces, with particular focus on the blockchain supported and the governance adopted.

Overview of NFT marketplaces

The empirical analysis has been decided to start from a general overview of the NFT marketplaces that have been included in the census, showing the numbers and the volume sales during the years and in the World.

Total marketplaces	Volume sales	Average	Median
100 marketplaces	50 billion	624 million	10 million

Table 1: total, average and median of volume sales of NFT marketplaces

The overview showed that the majority of the volume sales of $50 billion USD has been influenced by only a few NFT marketplaces, which dominated the market in the last years. These includes:

- OpenSea, the most popular NFT marketplace

- Axie Marketplace, the NFT platform of the game Axie Infinity

- CryptoPunks, a collection of 10.000 rare NFT digital figures

- Magic Eden, the largest NFT marketplace on the Solana blockchain

- Blur, a new NFT marketplace and aggregator

The distribution of the NFT marketplaces have been investigated, from 2017 to 2022. In the first three of the years analyzed, there was not much interest in the NFT market and only a few marketplaces were born, including the collection CryptoPunks and the marketplace OpenSea, both launched in 2017. But only in 2020, many events such as the pandemic and the crypto popularity made the market experience a high growth that led to an NFT artwork sold for $69 million USD. The peak arrived in the two years 2021-2022, when the market grew by more than 26.000%[1] in 2021 compared to 2020. Finally, in 2022, despite months of declining sales and falling prices during the second half of the year, the NFT sales volume in 2022 nearly matched the 2021 peak, generating around $25 billion USD. Then, the so-called crypto winter caused by the collapse of Terra's LUNA and UST, with the downfall of the crypto exchange FTX, made the NFT market drop as well. In the end of the year OpenSea remained the leading marketplace for NFT trades, with Blur after it, the new rival that incentivized NFT trades with the promise of upcoming token rewards, while Solana continued its up-and-down pattern.

The geographical analysis showed that America is the most active country in NFT platforms, where around the 80% of the volume sales analyzed takes place. It is followed by Asian countries such as Singapore and China, which take the 18%. However, the countries have not still made a regulation for NFT, so taxes are applied differently.

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[1] According to DappRadar

Business applications
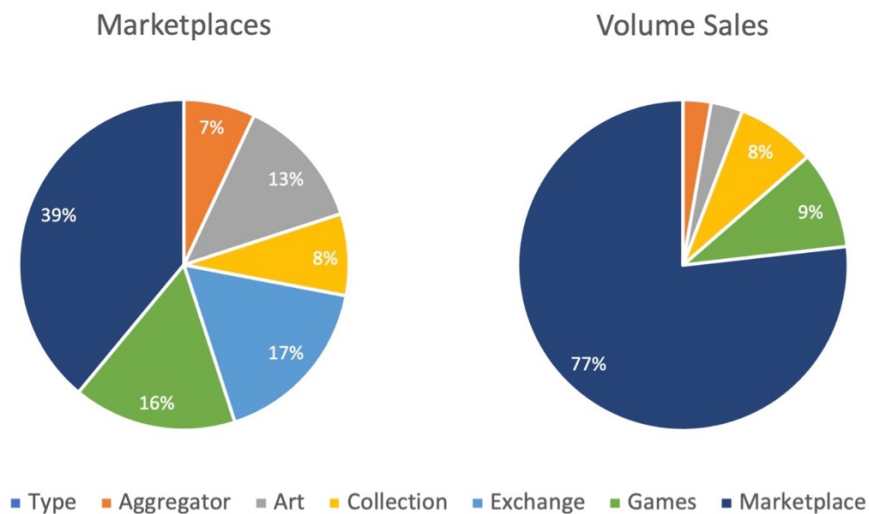
Figure 1: distribution of NFT marketplaces and volume sales by type

The marketplaces have been classified in six different classes:

- Marketplace: general NFT marketplace, open to everyone and many industries

- Gaming: platforms that sell NFTs used for gaming purpose

- Art: marketplaces that sell exclusive digital art collections

- Aggregator: platforms that browse NFTs from different platforms

- Collection: assortments of digital assets of the same style

- Exchange: the NFT marketplaces that belong to cryptocurrency exchanges

For each of these variables, the distribution of the number of NFT marketplaces and volume sales have been described and analyzed, in order to identify the most common and the most successful implementations, as shown in the following graph.

The category that saw the highest volume of sales is the open marketplace like OpenSea, where anyone can mint and sell NFTs. The gaming and art marketplaces are following, but aggregators like Blur are a new type of platform that is acquiring so much popularity lately and is radically changing the market.

Indeed, the commission fees collected by the platform for each transaction are set mostly to percentages under 1% but are getting set to zero in more and more marketplaces lately. The royalty fee, that is the percentage that goes to the original

creator of NFT during secondary sales, is usually set by the artist during the minting of the NFT, but a new trend is letting the buyer choosing the percentage of the transaction to send to the creator during the purchase. Most of the marketplaces offer three purchase methods: buying immediately the NFT for a fixed price; participate in an auction with a time limit; offer a bid, which can be later accepted or rejected by the seller. All of these can be done with cryptocurrency, but more and more marketplaces are implementing some auxiliar platforms such as MoonPay, that allow to buy NFTs with credit card. Finally, the majority of the marketplaces allow users to easily mint NFT directly on the platforms, without needing to have an advanced technical knowledge.

A focus on technological aspects

In the last section of this research, some more technical aspects have been examined. In fact, as reported in the literature review, the scientific papers on NFT are lacking in empirical analysis that examine how the technical elements are implemented in the various marketplaces. It has therefore been considered important to investigate the technological choices that the marketplaces analyzed have made, comparing the technical configurations adopted.

In particular, three aspects have been investigated: the blockchain platforms supported by NFT marketplaces, the implementation of a proprietary token and how they have been used in the governance, and the storage in which data about transactions are saved, whether on-chain or off-chain.

The majority of NFT marketplaces like OpenSea, do not support a single blockchain network, but they interface with various blockchains to provide their service, and this leads to a higher volume sale since they can reach a higher user base.

The blockchain that is supported by most of the NFT marketplaces is Ethereum, which has always been the most popular in this sector and last year has saw many improvements after the Merge and the transition from Proof-Of-Work to Proof-Of-Stake consensus mechanism. However, there are valid alternatives:

- BNB Chain, an Ethereum Virtual Machine that provides more efficiency

- Solana, the fastest blockchain supporting over 50.000 transactions per second

- Polygon, a blockchain that is compatible with ETH, allowing it to scale

- Immutable X, a layer 2 blockchain built on top of Ethereum

Subsequently, for each type of marketplace, the distribution of the blockchains have been analyzed, in order to identify the most popular blockchain networks for each industry.

Regarding the governance, the NFT marketplaces analyzed resulted to be split in two equal halves in centralized and decentralized organizations. However, the volume sales of centralized marketplaces were almost three times more than the ones of the DAOs. Centralized platforms are dominating now, but this may not persist, since the need for more neutral decentralized marketplaces is clear, as testified by the new entrant Blur. Decentralized aggregators are aiming to close this gap between centralized and decentralized market by offering better experiences. Subsequently, it was evidenced that decentralized platforms implemented DAO mainly through the introduction of a proprietary token, which can be used as a governance token to allow the owner to participate in the voting mechanism for future policies of the platform.

NFT marketplaces choose to save data whether:

- On-chain, directly on the decentralized ledger of the blockchain, which is updated every time a transaction occurs
- Off-chain, where an external storage is exploited for this purpose

The majority of the marketplaces resulted to save data in both ways, by saving the critical data on-chain, and the less relevant one on an external storage, in order to gain the advantages of both methods.

Regarding the standard supported by the platforms, the protocols supported the most were the ones offered by Ethereum:

- ERC-20, used for general tokens
- ERC-721, used for non-fungible tokens
- ERC-1155, which adds batch functionalities to ERC-721

Marketplaces that support different blockchains from Ethereum, offer different proprietary protocols which however are usually compatible with the Ethereum's ones.

Main findings and conclusion

The literature review has underlined the disruptive potential of NFT marketplaces technologies as well as the significant obstacles that still stand in the way of implementing distributed systems in current value chains, both from a technical and commercial perspective. In fact, there is still a great degree of uncertainty about the best choices to make when implementing an NFT marketplace in the real world.

The literature has identified NFTs as possible keys in technological innovation for the future of the metaverse, thanks to their proprieties that make them unique digital pieces that cannot be copied, nor substituted, nor subdivided.

The empirical analysis that has been carried out on NFT marketplaces had precisely the objective of providing information on the choices they have made, with the aim of identifying business and technical patterns common to successful platforms.

The most important findings that have been achieved are listed subsequently.

- The decentralized NFT marketplaces are growing. These are not popular at the moment, but they are closing the gap with the centralized platforms by offering a better experience to their customers. This can be reached with a simple and intuitive user interface and a faster registration that won't require to sign up a wallet in order to purchase NFTs. Moreover, mobile applications currently do not allow the users to purchase NFTs, but only to browse them.
- Aggregators are a new phenomenon that are changing the market, Blur overall. Indeed, its policies of nullifying the platform fees and making the royalty fees optional as the discretion of the buyer, have forced major players like OpenSea to review their policies in order to not lose their users.
- Ethereum is still the most popular blockchain network in this ecosystem, but other blockchains are offering faster transactions and better efficiency. For this reason NFT marketplaces seem to consider the Proof-of-Stake the best

consensus mechanism, which is supported by Ethereum. However, blockchains are introducing new consensus mechanisms, whether born from improvements of this one or done by scratch.

- Regulations that deal specifically with NFTs are lacking in the majority of the World. There are regulations about crypto assets that however exclude NFTs, which are not covered for topics like copyright and for which taxes application still result ambiguous.

- The future of this market is still uncertain, and it will be certainly influenced by the entrance of new important players, such as big tech companies like Amazon, which is expected to launch its proprietary marketplace in 2023, and the phenomenon of the metaverse.

This study has some implications for NFT artists, who are going to find a summary of the advantages and disadvantages provided by each marketplace, including the fees. The entrepreneurs will find interesting the insights regarding the business choices that the various platforms are making and can help them in taking technical choices such as the most suitable blockchain network for their purpose. NFT enthusiasts are going to be helped in the choice of the platform in which to make their investments.

However, the analysis of this thesis presents some limitations which may represent concrete opportunities for future research. For example, data about volume sales of NFT marketplaces that belong to cryptocurrency exchanges have been excluded from the database, since these could not be retrieved separately from the volume sales of the cryptocurrencies. Moreover, the inclusion of future platforms may change radically the statistics collected. Regarding the technical variables, the distribution of the tokens lacks a classification of their functionality. Finally, some individual areas may be interesting to be thorough, such as the fashion industry which is investing a lot in this technology, or the phenomenon of aggregators.

1 Introduction

1.1 General Overview

Non-Fungible Tokens (NFTs) are digital assets that represent objects like art, collectible, and in-game items. They are traded online and are generally encoded within smart contracts on a blockchain. Public attention towards NFT has exploded in 2021, when their market has experienced record sales, but little is known about the overall structure and evolution of its market.

At first sight, now it seems that NFTs' speculation is over. In 2022 the volume of trades of non-fungible token have collapsed of 92%[2], with a medium price that went down of 84%. These numbers have involved many sectors, including the metaverses based on blockchain, like Decentraland or the Sandbox, which exploit these tokens for the exchange of virtual lands at the center of their operation.

But as the hype cycle model teaches us, we may be only in the third phase of the life of the technology, and we can finally consider their main functionality: some useful digital certificates.

Non-fungible tokens in fact give you ownership of artwork, music, videos and other online collectibles. They exist on blockchains, the innovative technology that underlies cryptocurrencies like Ethereum. As NFTs' popularity has grown, the NFT market has climbed to more than $40 billion USD in value[3].

Research on NFTs is still limited, and focuses mostly on technical aspects, such as copyright regulations, components, protocols, standards, and desired properties; new blockchain protocols to trace physical goods; and the implications that NFTs have on the art world, in particular as they allow to share secondary sale royalties with artists.

NFT marketplaces are interpreting their own way to allow artists to create and sell their digital content and collectors to buy the items. Items exchanged on the NFT market are organized in collections, sets of NFTs that usually share some common features.

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[2] According to Cryptoslam, a specialized portal
[3] According to the 2021 NFT Market Report released by blockchain data company Chain Analysis

Collections can be widely different in nature, from sets of collectible cards to selection of art masterpieces, to virtual spaces in online games. Most collections can be categorized in six categories: art, collectible, games, metaverse, utility and other.

1.2 Aim & Objective

I am going to analyze data concerning trades of million NFTs between August 2022 and March 2023 obtained primarily from Ethereum and Solana blockchains. First, I am going to make a census of the NFT marketplaces and characterize the statistical properties of the market. Second, I am going to make semi structured interviews to some of the most important NFT marketplaces, mostly in Italy. Eventually, I am going to identify the main trends in the NFT marketplaces in order to forecast the future of the market.

The study is focused on answering these questions:

1) Will NFT still be relevant in the next years? Will they be the cause of launch in metaverse?
2) What will be the main characteristics of the NFT marketplaces in the future?
3) What will be the most relevant factors that will make a marketplace more successful than the others?

1.3 Significance of the study

In 2022 the NFT market has collapsed: the average price of non-fungible tokens sale has decreased by 92% since the beginning of May 2022. In fact, their trading volume fell 97% in September from a record high in January. The value of the transactions dropped to $466 million from $17 billion in September, since the start of 2022.

The decline in NFT trading volumes is part of a broader decline in the crypto sector as investors lose confidence in the asset's potential due to the increasing monetary policy tightening. Due to the rapid pace of monetary policy, investors are cutting off their exposure to speculative assets, contributing to a bigger decline in the crypto industry. Moreover, an inflated market was also, to some extent, responsible for the precipitous

drop in transaction values. Since November 2021, the market cap of the cryptocurrency industry has dropped by around $2 trillion.

Research on NFT is very limited. The scientists Kireyev and Lin investigate how selection biases or seller mispricing affects valuations based on hedonic machine learning models in NFT markets. Related works on physical asset valuation and price index construction has investigated how selling mechanisms determine valuation and how behavior affects market data and price indices. The NFT context differs from physical asset markets in its novelty and availability of data (on bidding as opposed to just prices and sales outcomes). Other work focuses on blockchains, decentralization, and their role in business more generally. I address research in NFT space and provide one of the first studies of NFT marketplaces to light on interpretations and identify the future trends of this market.

2 Literature Review

2.1 Historical background

The blockchain, the technology which the non-fungible tokens (NFTs) are based on, was created by Satoshi Nakamoto in 2008 to serve as the public distributed ledger for bitcoin cryptocurrency transactions. The implementation of the blockchain within bitcoin made it the first digital currency to solve the double-spending problem without the need of a third-party authority.

In 2012 the concept which NFTs were based around was introduced with the 'Colored Coins' in a paper by Meni Rosenfield, whose idea was to describe a class of methods for managing real-world assets on the blockchain to prove ownership of those assets. They were small portions of Bitcoins, but with an added 'token' element that determines their use, making them unique. For example, with them people bought precious metals, government bonds, cars, digital collectibles, access to digital channels and other cryptocurrencies. However, the limitations of Bitcoin meant that this concept could never be realized.

In 2014, developers Robert Dermody, Adam Krellenstein, and Evan Wagner launched Counterparty, an open-source protocol that extends Bitcoin's functionality. This platform enabled people to develop and trade assets on a decentralized ledger network and became the place for digital creation and transaction. Indeed, here were launched many important projects like Spells of Genesis (2015), Force of Will (2016) which begun the selling of trading cards and Rare Pepes (2016).

Moreover, on May 3rd, 2014, digital artist Kevin McCoy and Anil Dash minted the first-known NFT 'Quantum' on the Namecoin blockchain. 'Quantum' is a video clip made by McCoy's wife of a pixelated octagon that hypnotically changes color and pulsates in a way that reminds of an octopus. This was the first example of a link between a non-fungible, tradable blockchain marker to a work of art, via on-chain metadata). This was different from the multi-unit, fungible, metadata-less "Colored Coins" of other

blockchains and Counterparty.[4] Since its minting, Quantum has become one of the most important NFT in the art market, with a price tag of $7 million USD.[5]

Following these events, many experimentations and development occurred and there were platforms built on top of the Bitcoin blockchain. Since Bitcoin blockchain was never intended to be used as a database for tokens representing the ownership of assets, began the big shift for NFTs to the Ethereum blockchain, which was backed up with the introduction of a set of token standards, allowing the creation of tokens by developer. Indeed, the token standard is a subsidiary of the smart contract standard, included to inform developers how to create, issue and deploy new tokens in line with the underlying blockchain technology.

Indeed, In October 2015, the first NFT project, Etheria, was launched and demonstrated at DEVCON 1 in London, Ethereum's first developer conference, three months after the launch of the Ethereum blockchain. Most of Etheria's 457 purchasable and tradable hexagon tiles went unsold for more than five years until March 13, 2021, when renewed interest in NFTs sparked a buying frenzy and all tiles were sold for a total of 1.4 million USD. [6]

The term "NFT" became popular with the ERC-721 standard, first proposed in 2017 via the Ethereum GitHub, following the launch of various NFT projects that year.[7] The standard coincided with the launch of several NFT projects such as Curio Cards and rare Pepe.

In 2017 John Watkinson and Matt Hall released one of the most important projects for NFT community: CryptoPunks, what is now is an NFT collection with tokens worth millions of dollars started as a set of 10000 uniquely. Once they debuted to the public,

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[4] "The NFT Origin Story, Starring Digital Cats" – The Wall Street Journal, 2021

[5] "The beginning of NFTs – A brief history of NFT art" - https://www.zenofineart.com/blogs/news/the-beginning-of-nfts-a-brief-history-of-nft-art#:~:text=2012%2D2016%20%2D%20The%20Early%20History%20Of%20NFTs,-Long%20before%20Ethereum&text=On%20May%203rd%2C%202014%2C%20digital,manner%20reminiscent%20of%20an%20octopus.

[6] "The cult of CryptoPunks" – TechCrunch, 2021

[7] "EIP-721: Non-Fungible Token Standard" – Ethereum Improvement Proposal, 2021

they were rapidly snatched up. It was only secondary markets where they began to raise up big price tags they're associated with today.

But what pushed the popularity of NFTs most were CryptoKitties, a blockchain-based game where people can use Ethereum to adopt, trade and breed cats, storing them in crypto wallets. They were unveiled in 2017 by the Vancouver-based venture studio company Axiom Zen in the largest hackathon for Ethereum ecosystem. After its announcement the game became a viral sensation, becoming so popular that the mainstream media like CNN, MSNBC and NY Times reported this phenomenon of people making unbelievable profits which made NFTs gain much attention.[8]

NFT gaming and metaverse projects were in the spotlights and the first to break ground in this space was Decentraland (MANA), a decentralized VR platform on the Ethereum blockchain. Decentraland enables users to explore, play games, create, gather stuff, and more. Everything you find, earn, and build there is yours to keep on the blockchain.

Another essential contribution to rapid rise of NFTs are the marketplaces where people can mint, sell, trade, and buy their digital assets. There are many NFT platforms, but only a few dominate most of the market. OpenSea revolutionized the economy of NFTs. It all started in 2017 when founders Devin Finzer and Alex Atallah found out about CryptoKitties. After speaking with other enthusiasts, they launched the first version of OpenSea and billed it as "the first open marketplace for any non-fungible asset on the Ethereum blockchain".

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[8] "History of NFTs" - https://www.bueno.art/blog/history-of-nfts

Figure 2: Google Trend of the word "NFT"

Up to the middle of 2020, the NFT market's size remained largely steady, with an average of 60 000 US dollars transacted per day. The NFT market experienced rapid growth in 2020, with its value tripling to 250 million USD.[9] Beginning in July 2020, the market saw a sharp increase. By March 2021, it had grown by 150 times more than it had eight months earlier, with a daily total volume traded exceeding ten million US dollars. In the first three months of 2021, more than 200 million USD were spent on NFTs.[10]

2021 became the year of NFT and there was a huge explosion and surge in NFT supply and demand. One of the biggest factors in this boom was the huge change that occurred within art market and the industry at large, when prestigious auction houses Christie's and Sotheby's namely, not only took their auctions into the online world but also began selling NFT art. This led to Mike Winkelmann's, otherwise also known as Beeple, make Christie's record-breaking sale of "Everydays: The First 5000 days" NFT for $69 million USD dollars. According to Christie's, that eye-popping vaulted Beeple into the position of top three most valuable living artists and such a huge sale from such a prestigious auction house validated the NFT marketplace significantly.

In 2020, the U.S. Patent and Trademark Office received three trademark applications for NFTs. In 2021, the number of trademark applications raised to more than 1200. The

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[9] "The NFT Market Tripled Last Year, and It's Gaining Even More Momentum in 2021" – Morning Brew, 2021

[10] "NFTs Are Shaking Up the Art World – But They Could Change So Much More" - Time

growing list of brands being trademarked for NFTs includes NYSE, Stra Trek, Walmart, Ticketmaster, and Yahoo.

Digital artist Pak's crushed the Art Basel record by collection $91.8 million USD dollars on Nifty Gateway for his piece "The Merge". The piece was bought by 28,983 collectors who purchased 300,000 plus pieces units of the project.

The high cost shows the extent people are willing to go claim ownership of an original piece of digital art, and another knock-on effect was other blockchains such as Cardano, Solano, Tezos and Flow, getting involved and starting their own versions of NFTs. With these newer platforms for NFTs, some new standards were established in order to ensure the authenticity and uniqueness of the digital assets created.

Towards the end of the year, once Facebook rebranded as Meta and moved into the metaverse, the surge in NFT demand and especially within the metaverse was remarkable.

In May 2022, The Wall Street Journal reported that the NFT market was "collapsing". Daily sales of NFT tokens had declined 92% from September 2021, and the number of active wallets in the NFT market fell 88% from November 2021. While rising interest rates had impacted risky bets across the financial markets, the Journal said "NFTs are among the most speculative".[11]

2.2 Non-fungible tokens (NFTs)

A non-fungible token (NFT) is a unit of data stored in a blockchain that certifies a digital asset to be unique and therefore not interchangeable, while offering a unique digital certificate of authenticity and ownership for the NFT.[12] Indeed, it cannot be copied, substituted, or subdivided. The ownership of an NFT is recorded in the blockchain and can be transferred by the owner, allowing NFTs to be sold and traded. More broadly, an NFT allows to establish the "provenance" of the assigned digital object, offering indisputable answers to such questions as who owns, previously owned and created the

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[11] "NFT Sales Are Flatlining" – The Wall Street Journal 2022
[12] "Definition of NFT" - https://www.merriam-webster.com/dictionary/NFT"

NFT, as well as which of the many copies is the original. NFTs can be created by anybody and require few or no coding skills to create. Since NFTs are uniquely identifiable assets, they differ from cryptocurrencies, which are fungible.

Several types of data can be associated to an NFT including photos, videos, and audio. NFTs are now being used to commodify digital objects in different contexts, such as art, gaming, and sports collectibles. Originally NFTs were part of the Ethereum blockchain but increasingly more blockchains have implemented their own versions of NFTs.

Proponents of NFTs claim that NFTs provide a public certificate of authenticity of proof of ownership, but the legal rights conveyed by an NFT can be uncertain since the ownership defined in the blockchain has no inherent legal meaning and does not necessarily grant copyright, intellectual property rights, or other legal rights over its associated digital file.[13] An NFT does not restrict the sharing or copying of its associated digital file. An NFT does not restrict sharing or copying of its associated digital file and does not prevent the creation of NFTs that reference identical files.

An NFT (and, if applicable, the associated license to use, copy, or display the underlying asset) can be traded and sold on digital markets. The extralegal nature of NFT trading usually results in an informal exchange of ownership over the asset that has no legal basis for enforcement, and so often confers little more than use as a status symbol.

Unlike cryptocurrencies such as Bitcoin or Ethereum, NFTs are not mutually interchangeable, and so are not fungible but can work as cryptographic tokens. NFTs creation happen when blockchains concatenate records containing cryptographic hashes – sets of characters that identify a set of data – onto previous records, creating a chain of identifiable data blocks. This cryptographic transaction process ensures the authentication of the digital content by providing a digital signature that tracks NFT ownership. Data links that are part of NFT records, that for example may point to details about where the associated art is stored, can be affected by a link rot.

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[13] "How to create an NFT – Simply Explained" - https://eduwab.com/how-to-create-an-nft-simply-explained/

An NFT does not necessarily imply that the owner possesses intellectual property rights to the digital asset the NFT purports to represent. Someone may sell an NFT that represent their work, and the seller may not be prohibited from creating additional NFT copies of the same work. Certain NFT projects, such as Bored Apes, explicitly assign intellectual property rights of individual images to their respective owners. The NFT project CryptoPunks was a project that initially prohibited owners of its NFT from using associated digital artwork for commercial use, but later allowed such use upon acquisition of the collection's parent company.

The main properties and characteristics of NFT are:[14]

- Verifiability. The NFT with its token metadata and its ownership can be publicly verified with the blockchain technology.
- Transparency. The activities include minting, selling, and purchasing are publicly accessible. Within the data blocks, every transaction has been historically recorded and kept track of. This attribute eliminates the requirement for a third-party authentication technique by making it possible to trace the provenance of any NFT that is associated to an artwork.
- Availability. All the tokens and issued NFTs are always available to sell and buy, so the NFT system never goes down.
- Scarcity. The creator of an NFT gets to decide the scarcity of their asset.
- Tamper-resistance. The NFT metadata and its trading records are persistently stored and cannot be manipulated once the transactions are deemed as confirmed.
- Usability. The most recent ownership information is available for every NFT, and it is user-friendly and information clear.
- Atomicity. One atomic, consistent, isolated, and durable (ACID) transaction can be used to trade NFTs. The NFTs are capable of operating in a shared execution state.

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[14] "Non-Fungible Tokens (NFT) – Innovation beyond the craze" – Proceeding of Engineering & Technology Journal, 2021

- Tradability. Every NFT and its corresponding product can be arbitrarily traded and exchanged.

- Non-interoperability. Any asset may be located and is a distinct object within its own ecosystem. It is impossible for it to have the same representation in a similar setting.

- Indivisibility. An NFT is represented as a whole item and cannot be divided into smaller denominations.

- Indestructability. These assets are improved by the immutability of the blockchain. The ownership rights of the NFT are granted to the wallet or peer that has it because all the metadata contained in the blockchain through smart contracts cannot be copied, erased, or destroyed.

2.3 Technical Analysis

In this part I will analyze the NFT by a technical point of view. First, I will identify the core technical components that are used to construct NFTs. Then, I will present their protocols, standards, blockchains and consensus mechanisms. Successively, after providing a study case of the creation of a smart contract, I will analyze the opportunities and threats of NFT platform systems, and analyze the main protocols used by the NFT marketplaces.

2.3.1 Technical components

Figure 3: illustration of a non-fungible token generated by a smart contract

- Blockchain: a type of distributed ledger technology (DLT) that consists of growing list of records, called blocks, that are securely linked together using cryptography. [15] Each node contains a cryptographic hash of the previous block, a timestamp, and transaction data that are used to prove that the data existed when the block was created. Blockchain transaction are irreversible: once recorded, the data in any block cannot be altered retroactively without altering the subsequent blocks. The main goal of this technology is the absence of a central authority, which can be substituted by a peer-to-peer (P2P) network. Every node of the network shares the same chain of blocks, which is an immutable ledger. Since every information inserted in the block cannot be modified, the installing of each block must be verified with a mechanism of consensus. This can be implemented in various ways, such as the Proof-Of-Work and Proof-Of-Stake. Transactions are sent all over the network and a miner verifies them as valid and inserts them in a block. Blockchain can be public, permissioned, or private. In public blockchains like Bitcoin and Ethereum everyone can join the network and no authorization is required to execute a transaction, vary transactions or create a new block. In permissioned blockchains like Hyperledger a node can join the network after receiving the authorization

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[15] "Blockchains: The great chain of being sure about things" – The Economist, 2015

from a central authority. Finally private blockchains are not visible from outsiders and are managed by a trusted central authority that determines who can enter the network.

- Smart Contract. Are computer programs that are automatically executed in response to some external events according to a predefined contract. The idea to use them in a blockchain was introduced with Ethereum blockchain. They are executed by the nodes of the network and need a consensus in order to result valid. Then one or more transactions are generated. Their main goal is to accelerate, verify or execute digital negotiation. Since the blockchain is immutable, smart contracts must be deterministic and always guarantee the same outcome, so they adopt Turing-complete scripting languages to achieve complicated functionalities and execute though state transition replication over consensus algorithms to realize final consistency. The smart contracts enable unfamiliar parties and decentralized participants to conduct fair exchanges without a trusted party.

- Address and Transaction. A blockchain address is a unique identifier for a user to send and receive assets. It is made up of a set number of alphanumeric characters that are created using a set of public and private keys. To send NFTs to another address with a valid digital signature, the owner must demonstrate that they are in possession of the appropriate private key. This is performed with a cryptocurrency wallet and is represented as sending a transaction to involve smart contracts in the ERC-777 standard.

- Data encoding. The process of converting data from one form to another. In the main blockchain systems they employ hex values to encode transaction elements such as the function names, parameters and return values. The owner of the NFT is the owner of the original piece of hex values signed by the creator. Anyone can copy the raw data, but only one person can claim the ownership of the property.

2.3.2 Standards

Standards outline how to create NFTs on a particular blockchain. They give developers the guarantee that assets will behave in a specific way and describe exactly how to

interact with the basic functionality of the assets. The smart contract and the properties of the token it issued are defined by a token standard. In this part I clarify token standards related to NFT, including ERC-20, ERC-721, ERC-1155 and others. ERC-20 maps address to amounts, ERC-721 maps unique IDs to owner, and ERC-1155 has a nested mapping of IDs to owners and amounts.

ERC-20. It introduces the concept of fungible tokens that can be issued on Ethereum after satisfying some specific requirements. This standard makes every token the same as another one, with the same type and value. This gave rise to the hype of Initial Coin Offering (ICO) that started in 2015.

ERC-721. It was the first standard for representing non-fungible digital assets. This type of token is unique that can be distinguished from another token. Pioneered by CryptoKitties, ERC-721 is an inheritable Solidity smart contract standard, meaning that developers can easily create new ERC-721 compliant contracts by importing it from the Open Zeppelin library. It provides a mapping of unique identifiers (each of which represents a single asset) to addresses, which represent the owner of that identifier. Specifically, every NFT has a uint256 variable called tokenID, and the pair of contract address and uint256 tokenID is globally unique. ERC-721 also provides a permissioned way to transfer these assets using the *transferFrom* method. The following two methods check who owns what asset and a way to move assets around. There are a few other functionalities to the standard, some of which are very important for NFT marketplaces, but the core is quite basic. For example, the tokenID can be used as an input to generate special identification such as image in the form of characters.

```
interface ERC721 {
  function ownerOf(uint256 _tokenId) external view returns
(address);
  function transferFrom(address _from, address _to, uint256
_tokenId) external payable;
}16
```

Figure 4: interface of standard ERC-721

ERC-1155. It brings the idea of semi-fungibility, by extending the representation of both fungible and non-fungible tokens, inheriting the functionality of ERC-721. Pioneered by the Enjin team, IDs do not represent single assets but classes of assets. It provides an

interface that can represent any number of tokens. In previous standards, every tokenID in contract only contains a single type of tokens. For instance, ERC-20 make each token deployed in separate contracts. As well, ERC-721 deploys the group of non-fungible tokens in a single contract with the same configuration. ERC-1155, on the other hand, expands the capabilities of tokenID by allowing each of them to individually represent various configurable token kinds. The field may contain its customized information such as metadata, lock-time, date, supply, or any other attributes.

```
interface ERC1155 {
  function balanceOf(address _owner, uint256 _id) external view
returns (address);
  function balanceOfBatch(address calldata _owners, uint 256
calldata _ids) external view returns (uint256 memory);
  function transferFrom(address _from, address _to, uint256 _id,
uint256 quantity) external payable;
}
```
Figure 5: interface of standard ERC-1155

For example, an ID might represent "hats", and a wallet could own 100 of these hats. In this case, the *balanceOf()* method would return the number of hats owned by a wallet, and a user can transfer any number of these hats by calling transferFrom with the "hat" ID. One advantage of this type of system is efficiency. With the ERC-721 to transfer many assets the user would need to modify the smart contract's state by calling the *transferFrom()* method for all the unique tokens. With ERC-1155, the developer need only to call *transferFrom()* for all the assets by performing a single transfer operation. This increased efficiency comes with a loss of information, since we can no longer trace the history of an individual asset. Moreover, ERC-1155 provides a superset of ERC-721 functionalities, meaning that an ERC-721 asset could be built using ERC-1155. This could happen by separating ID and quantity one for each asset. Due to these advantages, there has been a growing adoption of the ERC-1155 standard.

Its basic functionalities are:

1. Batch transfer of multiple assets in a single transaction
2. Get the balance of an entire batch of assets with a single query

3. Allow for batch approval of all tokens sent to an address

ERC-998. It is an extension of ERC-721. It is composable, which provide a template by which NFTs can own both non-fungible and fungible assets, allowing the ERC-998 token to manage other tokens within itself. It can hold ERC-721 and ERC-20. This makes it possible to create complex compositions out of conventional assets that may be transferred in a single transfer. The main difference between ERC-998 and ERC-1155 is that ERC-998 merges NFTs and fungible tokens into one NFT, while ERC-1155 registers NFTs and fungible tokens into a single smart contract. There have only been several composable NFTs deployed on the internet, but they may gain importance in the future.[16]

Non-Ethereum standards

Ethereum is the most popular chain, but there are several other NFT standards emerging on other chains, such as Binance Smart Chain, DGoods, pioneered by Mythical Games, and the Cosmos project.

Binance Smart Chain (BSC). It is compatible with the Ethereum blockchain, which allow porting application with them. The public wallet address is the same on Binance Smart Chain and Ethereum blockchains. BEP-20, BEP-721 and BEP-1155 are extensions of ERC-20, ERC-721 and ERC-1155, respectively. They function similarly to their Ethereum counterparts. The main differences are that transaction costs are lower in Binance Smart Chain compared to Ethereum and Binance Smart Chain processes transaction are 4.3 times faster than Ethereum.

SIP-009. SIP-009 is the standard used by Stack blockchain programming layer, which settles onto the Bitcoin blockchain, enabling the use and creation of smart contracts, buying, selling, and minting of NFTs secured by Bitcoin.

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[16] "NFT's standards of top blockchain of 2023" – AIMultiple, 2023 - https://research.aimultiple.com/nft-standards/

2.3.3 Programming languages

A programming language is a system of notation for writing computer programs. A lot of popular coding languages can be used in blockchain development. Afterwards are listed the most popular programming languages used for blockchain development.

Solidity.[17] Solidity is an object-oriented and statically-typed curly-braces programming language designed for developing smart contracts that run on Ethereum. Solidity is designed based on existing programming languages like C++, Python, and JavaScript, so it uses similar language structures found in these languages, most likely to make it easy for developer adoption. Solidity, being the first smart contract programming language, has wide market adoption and is being used to build many decentralized applications. It was developed to write smart contracts on Ethereum and runs on the Ethereum Virtual Machine. As a relatively young language, Solidity is advancing at a rapid speed. It presents many advantages, for instance Solidity has a large, accessible community, since it was the first smart contract programming language. Moreover, it is Turing-complete, so it's not limited to running just a handful of algorithms, but it can be used to compute all computable functions. Then it offers concepts that are available in most modern programming languages. It has functions like string manipulation, classes, variables, arithmetic operations. In addition, Solidity supports mapping data structures, which act as hash tables and consist of key types and key value pairs. Finally, most of its syntax was borrowed from programming languages like Python, C++, and JavaScript, so developers who already know who to program with these languages will find it much easier to learn Solidity. However, since it is a new language, and even though the community has been helping with library development and its tools, there's still many things in the language that needs to be implemented. Blockchains that are using solidity are Ethereum, Binance Smart Chain, Tron, Avalanche, Tendermint, Counterparty and Hedera.

Rust. One of the most beloved programming languages in the last five years.[18] Rust is a low-level and statically-typed programming language that is fast and memory-efficient.

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[17] "Solidity" - Soliditylang.org
[18] According to Stack Overflow surveys

Its main advantages are performance, reliability, productivity, simplicity and complexity. It is used in one of the fastest blockchain, Solana.

JavaScript. A general-purpose programming language. Since it is an entry-level language, most blockchains tend to create a JavaScript wrapper or library to allow developers to easily enter the ecosystem and start building products as soon as possible. Hyperledger Fabric is a blockchain that allows you to build a smart contract with a few programming languages, including JavaScript. The Solana Foundation also built JavaScript wrappers around Solana Rust programs that allow JavaScript developers to start building products on the blockchain as soon as possible. Its main advantage is its popularity with a lot of community support. However, since it is a dynamic typing language, it lacks type safety.

2.3.4 Blockchains

A blockchain is a distributed ledger that allows for secure, transparent, and tamper-proof record-keeping. The technology has been widely used to create digital assets, like cryptocurrency or non-fungible tokens.

In this section, I am going to explain the main characteristics that differentiate the various blockchains for NFT development, then I will present the most popular blockchains which marketplaces are based on.

Transaction speed. Transaction speed is crucial to make sure that the blockchain can handle a large number of transactions at a time. In that way, many users will be able to mint and transfer many NFT at the same time. The efficiency of the blockchain network will affect positively the performance of the projects and delays will be avoided during high-traffic hours.

Transaction costs. There are fees that users pay to send a transaction or interact with a smart contract on a blockchain network. There are two main reasons users need to pay fees when sending a transaction. The first reason Is to pay miners or validators, also known as nodes, for securing the network. The second reason is to enable the operation of smart contracts, through the so-called gas fees, which will be explained better in the next section. Transaction fees are not static, and they vary based on many variables. One of these variables is the transaction speed of the blockchain. Transactions with higher

fees gets prioritized by nodes, reducing the time it takes for them to arrive. On the other hand, transactions with lower fees take longer to validate since nodes do not prioritize them. When the network Is busy, you may have to pay higher fees to outbid users and ensure that validators prioritize your order. Otherwise, it may get rejected.

Security. The security of a blockchain network is another critical aspect. A blockchain can get hacked if it is not fundamentally strong enough. In such cases, all sorts of users, including investors, traders, and creators, end up losing their funds and data. An example is the hack that Ronin has suffered in March 2022, when it was hacked for a value of over 600$ million USD dollars.[19]

Smart contracts. All NFTs on every blockchain rely on smart contracts. They are used to set up terms and conditions for transactions on a blockchain. When these terms are met, the transfer is automated and processed without the need for a third-party validator. Smart contracts are used for NFT's minting process (creation) and to assign ownership of the token. When a new non-fungible token is minted, the smart contract automatically sets the creator as the owner. NFT smart contracts can transfer the token to new owner when a sale is made.

In some cases, NFT marketplaces use a suite of smart contracts for auctioning NFTs. These platforms may temporarily hold token ownership until predetermined conditions, such as a specific date or bid price, are met. Smart contracts can also give NFTs utility or deactivate them. For example, a gaming company could use blockchain technology to incorporate NFTs into their digital trading card game. Blockchains with well programmed and sophisticated smart contracts tend to be more secure and functional for users.

2.3.4.1 Consensus mechanism

It is the system of protocols, incentives, ideas, and algorithms that blockchains use to validate the authenticity of transactions and governance of the blockchain. By consensus, we mean that a general agreement has been reached. It enables trust and maintain the security of the underlying blockchain. Indeed, it ensures that all legitimate

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[19] "The aftermath of Axie Infinity's $650M Ronin Bridge hack" – Cointelegraph, 2022
https://cointelegraph.com/news/the-aftermath-of-axie-infinity-s-650m-ronin-bridge-hack

transactions are recorded on the blockchain and each copy of the blockchain contains all valid transactions. It influences how transactions are verified, how much energy is used, network fees, transaction speed and other details. The consensus mechanism ensures that all miners, the computers that validate new transactions on blockchains, agree on the next block of transactions and distributes the information in each new block to all other miners. Anyone can download a copy of the blockchain to their device as node. Every copy of the ledger matches exactly. The consensus mechanism ensures the continued agreement on which wallet owns which assets. The main advantages that it brings is a synchronization of data between all participating users, the creation of a secure environment, and the decrease of the barriers to anyone who wants to participate as a miner or operate its own node.

There are different types of consensus mechanisms with various benefits and drawbacks. [20]

- Proof-of-Work (PoW). Miners compete against each other to validate the next transaction block and earn a reward, by completing a hard to solve puzzle but easy to check. The race is won by the computer which is able to solve this math puzzle the fastest. This produces the cryptographic link between the current block and the block that went before. The canonical chain is then determined by a fork-choice rule that selects the set of blocks that have the most work done to mine them. This is a highly energy-intensive consensus mechanism but brings a high degree of trust. The network is kept secure by the fact that you'd need 51% of the network's computing power to defraud the chain.
- Proof-of-Stake (PoS). Cryptocurrency achieves distributed consensus. Those in the largest holding of the network's currency become validators, who create new blocks. It derives it security from a set of rewards and penalties applied to capital locked by stokers. This incentive structure encourages individual stokers to operate honest validators, punishes who do not, and creates an extremely high

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[20] "Consensus Mechanisms" – Ethereum.org
https://ethereum.org/en/developers/docs/consensus-mechanisms/

cost to attack the network. This enables faster and lower-cost transactions. The main types are randomized coin selection and coin age-based selection.

- Proof-of-Authority (PoA). Used mainly in private companies, it is an algorithm that delivers comparatively fast transactions through a consensus mechanism based on identity as a stake. The process is automated and does not require validators to be constantly monitoring their computers. It is considered more robust than PoS, and assurances are based on reputation and authority rather than public consensus as with other mechanisms.

- Delegated Proof-of-Stake (DPoS). A variation of the Proof-of-Stake that allows users of the network to vote in delegates who then verify and validate blocks to produce. After they successfully produced a block, the validators may then distribute their block rewards to those who voted for them.

- Proof-of-Capacity (PoC). It relies on a computer's available hard drive storage space for a decentralized block verification and generation process. This is in contrast to using the mining device's computational power (as in PoW) or the miner's stake in the cryptocurrencies (as in PoS). The main benefit is its efficiency. Some blockchain that run this consensus mechanisms include Stoj, Chia, Burst and Spacemint.

- Proof-of-Activity (PoA). It is the combination of Proof-of-Work and Proof-of-Stake that tries to take best aspects of both of the systems. It begins like a Proof-of-Work system, with various minters trying to outpace each other with higher computing power to find a new block. But then, after a new block has been successfully mined, the system switches to resemble a Proof-of-Stake mechanism, with the newly found block containing only a header and the miner's reward address.

- Proof-of-Elapsed Time (PoET). It uses a random timer generated by a trusted execution environment (TEE) that operates independently at every node to randomly assign the block verification to a miner. It was originally developed by Intel engineers, but never formally defined or analyzed. Another similar consensus mechanism is Proof-of-Luck (PoL), and both of them are considered Nakamoto-style consensus mechanisms.

- Proof-of-Burn (PoB). It is a type of Proof-of-Work (PoW) that incentivizes miners to burn a portion of their reward in order to receive block reward. So, miners periodically burn coins, a process of permanently deleting or eliminating that specific coin, as an incentive to reduce the number of coins from circulation, and to increase the value of those remaining, by preventing inflation in this way.

2.3.4.2 Off-chain vs On-chain

The blockchains can save transaction's data providing transparency for both recipient and the grantee without a trusted third party in two different ways: on-chain or off-chain. In recent years, organizations started managing data for blockchain-based solutions as either on-chain or off-chain storage techniques by storing data in a private or public blockchain service. The former provides a secure and open solution for transactions on-chain. For users seeking speed, anonymity, and cost efficiency, conducting a transaction off-chain might make sense. On-chain transactions offer greater security and transparency because they're verified and recorded on a public distributed ledger that cannot be changed. However, blockchain transactions may include high fees and slow processing time, depending on the network's verification method. Off-chain transactions are confirmed outside of the main blockchain network, often resulting in a cheaper and faster process for the user.

On-chain transactions are carried out on a blockchain from start to finish, by going through many steps. You must hold data on the blockchain and have it locked in an address in order to conduct an on/chain transaction. To transmit a token to a recipient's address, you must first generate a private key. Once verified, the transaction is recorded on a blockchain's network public ledger and then disseminated. In this method the block is sent to the node and then validated by nodes and eventually added to the blockchain. The process provides a high level of security and transparency because transaction data is public and constantly reviewed and updated by the network of miners and validators. These kinds of transactions must take place in a small amount of time in order to maintain blockchain speed and validity. The benefits of on-chain transactions include security, since data stored in the blockchain is encrypted end to end and cannot be

altered once recorder; decentralization, because blockchains are not subject to a central authority for governance; transparency, since transactions are simultaneously recorded and validated in multiple locations, and anyone can trace the unique wallet associated to a transaction and view its activity. However, the intricacy of the process means that it takes some time to process each transaction and add it to the blockchain. So, the disadvantages are that transactions are slow, depending on the volume of transactions in the queue to be processed, for which the transaction fees and the power usage of computational power and energy become high.

In contrast, off-chain transactions transfer some of the work from a blockchain ecosystem on an off-chain network. The users agree that a third party will handle validating and authenticating transactions. The off-chain approach can be used to perform coupon-based transactions. Off-chain systems tackle a blockchain's network scalability issue by facilitating faster and cheaper transactions. One off-chain transaction method is to employ a layer 2, which is a second blockchain build on top of the main blockchain (mainnet) to help mainnet scale in speed and cost. This takes transactions off the main chain to another chain. In general, off-chain transaction have faster transaction speed, since they do not have to wait for the main blockchain network to confirm a transaction, lower costs since no process of validation is needed, and more privacy since data is not publicly broadcast to the network. However, this leads to less transparency, the need of an intermediary to trust, and less security because operations out of the blockchain can be more vulnerable, since can be altered. There are numerous off-chain protocols available as compared to on-chain protocol. The Lightning network is a layer 2 protocol built on top of Bitcoin's blockchain that allows users to conduct infinite transactions quickly and cheaply. The Liquid network is a sidechain protocol, meaning that while data is saved on the Bitcoin blockchain, transactions are processed independently. Custodial services refer to third-party services that keep and safeguard tokens on behalf of institutional investors who transact huge amount of cryptocurrency.

On-chain transactions	Off-chain transactions
Deploy blockchain technology to execute the transactions	Do not require blockchain technology to execute transactions
Transaction fees to pay depending on the transaction size and the volume of traffic	No additional fees are charged for processing the transaction
Speed can slow down due to the network congestion	Speed is rapid and instantaneous, thanks to lower utilization of data on the chain
Security is ensured by the immutability of the Blockchain ensures. Image is immutable.	Relatively less secure: two levels of risk (chain and centralized server). Image is editable in any moment.
Reliability is appropriate	Reliability is relatively less secure: higher possibility of corrupted files in the long term

Table 2: advantages and disadvantages of on-chain and off-chain transactions

2.3.5 Blockchain cases

Now I am going to list and describe the most popular blockchain networks used for NFT development.[21] By November 2022, Ethereum is the dominant home of NFT activity and trading, making up 76% of all NFT volume. This is followed by Axie Infinity's sidechain Ronin with 11% share of trading volume, Solana with 7%, Flow with 3%, and Polygon with 1%.[22]

Ethereum.[23] Ethereum is a decentralized, open source, blockchain with a smart contract functionality. Launched in 2015 by Vitalik Buterin, Ethereum is the most popular blockchain for NFT development. Indeed, it is the biggest and most well-known blockchain and cryptocurrency after Bitcoin and was the first blockchain to introduce smart contracts, the technology that made non-fungible token possible. Today, Ethereum presents more than 80,000 NFT collections[24], making up 76% of All NFT volume.[25] Ethereum allows anyone to deploy permanent and immutable decentralized applications onto it, with which users can interact. It is a permissionless, non-hierarchical

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[21] "Top blockchain used in NFT development" – Blockchain-council.org, 2022
https://www.blockchain-council.org/nft/top-5-popular-blockchains-used-in-nft-development/#:~:text=Ethereum%20is%20the%20most%20popular%20blockchain%20for%20NFT%20development%20for,community%20of%20developers%20and%20users
[22] According to Forbes, 2022
https://www.forbes.com/sites/leeorshimron/2022/09/17/ethereums-major-upgrade-creates-big-questions-complications-for-nfts/?sh=6f3e1a52204d
[23] "Ethereum" – www.ethereum.org 2023
[24] According to CoinMarketCap
[25] According to Cryptoslam.io

network of computers (nodes) that build and come to a consensus on an ever-growing series of "*blocks*", or batches of transactions. Each block contains an identifier of the chain that must precede it if the block is to be considered valid. Whenever a node adds a block to its chain, it executes the transactions into the block in the order they are listed, each of which may alter the ETH balances and other values of the accounts, which collectively known as the "*state*" are maintained on the node separately from the blockchain in a Merkle tree.

Each node communicates with a relatively small subset of the network: its peers. Whenever a node includes a new transaction in the blockchain, it sends a copy of the transaction to each of its peers, who then send a copy to each of their peers, and so on. Some nodes called miners maintain a list of all these new transactions and use them to create new blocks to send to the network. Whenever a node receives a block, it checks the validity of the block and then adds it to the blockchain and executes all of its transactions. Since block creation and broadcasting are permissionless, a node may receive multiple requests for a block to be the successor of a certain block. In that case, the node drops the shortest one and the chain to be considered canonical is the longest one.

The Merge.[26] On 15 September 2022, Ethereum transitioned its consensus mechanism from proof-of-work (PoW) to proof-of-stake (PoS), which cut Ethereum's energy usage by 99,95%. In this process, the original execution layer of Ethereum (the Mainnet that existed since genesis) joined its new proof-of-stake consensus layer, the Beacon Chain. It eliminated the need for energy-intensive mining and instead enabled the network to be secured using staked ETH, bringing more scalability, security, and sustainability. In this way, the two Ethereum networks merged together, and the community refer to "Eth1" as the execution layer, which handles transactions and execution, while refer to "Eth2" as the consensus layer, which handles proof-of-stake consensus.

Proof-of-work and proof-of stake are the two most popular ways of processing cryptocurrency transactions by adding new blocks of transactions to the historical record. The main difference is that proof-of-stake relies on staking, which involves

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[26] "The Merge" – Ethereum, 2022
https://ethereum.org/en/upgrades/merge/

pledging some cryptocurrency to help vouch for the accuracy of newly added information. In the mechanism of proof-of-work, the creation of new blocks is bound to finding the solution of a computational puzzle. It is an asymmetric puzzle, because the solution is hard to compute for miners but easy to verify. The complexity is typically dynamic in the sense that it changes based on the computational power of the network to grant the creation of new blocks with a constant interval. Now, the proof-of-stake is a type of consensus mechanism by which a cryptocurrency blockchain network achieves distributed consensus. The main types are randomized coin selection and coin age-based selection. It was first introduced as an alternative to proof-of-work, that causes a high electricity consumption, whereas proof-of-stake does not.

The successful Merge, along with subsequent updates planned in coming months dubbed Surge, Verge, Purge, and Splurge, should help the network protect its head start against competitors that offer chapter and faster transactions. However, upset by the upgrade cutting them out of the network, a group of Ethereum miners have banded together and launched a forked version of the Ethereum chain that retains proof-of-work, the new chain being called Ethereum PoW (ETHW). For NFT holders this means that they may now own duplicates of their assets, but their value will depend on the level of exchange support and overall adoption of this forked network.[27]

Solana. Solana is one of the fastest blockchain and competitor to Ethereum blockchain. Proposed in November 2017 by Anatoly Yakovenko, its first block was created in March 2020.[28] Its design is based on the proof-of-stake (PoS) consensus model but improves it with a mechanism called proof-of-history (PoH), which uses hashed timestamps to verify when transactions occur without a trusted source of time. This allows the blockchain to execute 65,000 transactions per second (while Ethereum can handle less than 15 transactions per second) at a relatively modest cost, around $0.00025 USD (while Ethereum average transaction fees are around $1.68 USD). Since proof-of-history does not need to expend processing power before validating various timestamps, validators can be in charge of their clocks and speed up the transaction validation process. Solana's

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[27] "Ethereum's Major Upgrade Creates Big Questions, Complications for NFTs" – Forbes, 2022
https://www.forbes.com/sites/leeorshimron/2022/09/17/ethereums-major-upgrade-creates-big-questions-complications-for-nfts/?sh=6f3e1a52204d
[28] "Explorer | Solana" – explorer.solana.com, 2022

smart contracts are published on-chain using Rust, C and C++ programming languages. The cryptocurrency that runs on Solana blockchain SOLUSD at one point had a market capitalization of over $66 billion USD, but despite its popularity it did not avoid the cryptocurrency crisis of 2022 and by October 3, 2022, and dropped to about $11.71 billion USD in market capitalization. The most popular NFT projects on Solana are Degenerate Ape Academy, Solana Monkey Business, Solpunks, and Frakt. The blockchain also enables the creation of advanced marketplaces like Solanart.io and DigitalEyes.market, SolSea and Megaplex.

Flow. Flow is a blockchain platform that originally was designed for gaming purposes but has expanded since its launch in 2020 in conjunction with the digital collectible marketplace NBA Top Shot, that specializes in basketball cards. Developed by the Dapper Labs in 2019, the team behind the development of CryptoKitties, Flow is primarily focused on sustainability, scalability, composability, and user experience. The network is based on the proof-of-stake consensus model, enabling it to execute about 10,000 transactions per second. Moreover, it has two cost structure per transactions: one for opening an account, which starts at 0.001 FLOW and one for transactions, which starts at 0.000001 FLOW. The most important Flow-powered projects apart from the already mentioned NBA Top Shot are TuneGO, BloctoBay and Xtingles.

Immutable X. It is a layer 2 scaling solution for NFT collections running on Ethereum, developed by the gaming studio Immutable. Founded in 2018, the firm has released the crypto game Gods Unchained, based on collectible cards, which however did not fit in the Ethereum ecosystem, since required an efficient and low cost blockchain to enable a continuous exchange between the players. The platform exploits a zero-knowledge-proof rollup, a layer 2 protocol for validating transactions on the Ethereum blockchain, for which transactions can be executed in group and not one by one, approved by a smart contract. More detailly, instead of adding all the transaction data to the blockchain, ZKRollup consolidates hundreds of transactions into a single zero-knowledge proof called the ZKSTARK proof, which stands for Zero-Knowledge Concise and Transparent Knowledge Discussion. After the transaction is stacked, the proof is sent to the blockchain and validated by the smart contract, which maintain all transaction details at Layer 2. Therefore, the evidence can be quickly verified because it does not

contain the complete data for each transaction. Another feature is the set of REST APIs that can simplify complex blockchain interactions, without the need to interact directly with the smart contract. This allows users to enjoy a seamless experience of minting and trading digital collectibles, involving zero gas fees, carbon neutrality, processing of 9000 transactions per second and access to instant trades, games, and applications without any compromise. Moreover, Immutable X ensures the trade security of NFT projects through a well-structured decentralized ecosystem.

Ronin.[29] It is an Ethereum-linked sidechain developed by Sky Mavis built specifically for games. This extension allows players to play Axie Infinity, a popular play-to-earn NFT game, and other decentralized applications (DApp). It was developed to process transaction more quickly the Ethereum. However, in March 2022, it was hacked for over 173,600 Ether and $25.5 million USD Coin for a combined value of over $600 million USD. The hackers managed to get access to private keys to five validator nodes. The root cause for the exploit could be traced back when Axie DAO gave access to Sky Mavis to sign-off on transactions on its behalf to mitigate the volume, but since the access was never revoked, a backdoor access was left open for the hackers. The developers behind the game have then raised $150 million USD to reimburse the affected users. In spite everything, at the time of the research, Axie Marketplace is still one of the most popular marketplaces in the NFT market.

BNB Chain.[30] Binance's proprietary chain, BNB (which stands for "Build and build") comes from the joining of Binance Chain and Binance Smart Chain (BSC). It is neither a Layer 2 scalability protocol nor an off-chain solution. It is an Ethereum virtual machine (EVM), a compatible blockchain that serves as an alternative to the Ethereum network and facilitates the formation of smart contracts and enabling support for a wide range of Ethereum-based applications as well. It uses a unique consensus mechanism known as proof-of-staked-authority (PoSA) for validating transactions and governing its network. The system combines delegated-proof-of-stake (DPoS) and proof-of-authority (PoA)

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[29] "Ronin Ethereum Sidechain" – Axie Infinity, 2021
https://whitepaper.axieinfinity.com/technology/ronin-ethereum-sidechain
[30] "Introducing BNB Chain: The Evolution of Binance Smart Chain" – Binance, 2022
https://www.binance.com/en/support/announcement/introducing-bnb-chain-the-evolution-of-binance-smart-chain-854415cf3d214371a7b60cf01ead0918

consensus algorithms. The blockchain has its own token standard, BEP-721, to facilitate the development of NFTs. It can handle 300 transactions per second.

Cardano. Created by one of Ethereum's co-founders Charles Hoskinson, it is the seventh largest blockchain in the world, with a market capitalization of $11 billion USD.[31] Cardano is based on the distributed proof-of-stake consensus mechanism and focuses on creating a robust ecosystem for developing decentralized applications and NFTs. The blockchain is divided in two layers: the Cardano Settlement Layer (CSL), used to transfer ADA (Cardano's native token) between accounts and record transaction; the Cardano Computation Layer (CCL), which contains the smart contract logic used by developers to move money. Although it currently processes around 250 transactions per minute, with its Layer 2 scaling protocol the blockchain can potentially reach a transaction speed of up to 2 million transactions per second. Popular Cardano-based NFT projects include CardanoKidz, Spacebuds, Professor Cardano and CryptoMayor. The first Cardano-powered NFT is Cadalabs, released in October 2021.

EOS. EOS blockchain employs the delegated-proof-of-stake (DPoS) consensus algorithm and can handle 4,000 transactions per second. Regarding price structure, EOS theoretically does not charge any gas or transactional costs. In 2020, EOS launched a new NFT standard called AtomicAssets, which alleviates common usability issues by not needing any RAM from the user. Some of the most well-known NFT collections on EOT blockchain are AtomicMarket, Upland, Crypto Dynasty and Blockchain Cuties.

WAX. Worldwide Asset Exchange. It is a sidechain of EOS, a blockchain that have adopted the main features of a consensus protocol but have made some changes to solve some weak points of the original blockchain. These sidechains differ from the various forks because they create a chain from scratch, without forcing the main chain to "fork" and follow one or other ideology. Born with the intent to create and buy NFTs in a convenient and secure way. It uses the Delegated Proof-Of-Stake (DPoS) consensus mechanism and therefore the users who vote the block producers are members of the

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[31] According to CoinMarketCap during the time of the research.

WAX guild. It is based on the EOS blockchain, and it is linked to one of the most widely used wallets, WAX Cloud Wallet.

Theta. A mainnet blockchain built for decentralized peer-to-peer video delivery. Traditional video streaming services suffer from the "last mile" delivery, that cause bottlenecks because of the distance of the data centers from the viewers. Theta's solution is a peer-to-peer network in which viewers are incentivized to share their excess computing and spare bandwidth resources. It runs on a modified Proof-of-Stake (PoS) consensus mechanism known as Multi-Level Byzantine Fault Tolerance (BFT), which relies on a small subset of nodes to speed up approvals.

Waves. A Proof-of-Stake (PoS) blockchain network, decentralized exchange, and wallet that allows individuals to easily create and launch their own customed crypto token as well as exchange and trade cryptocurrencies. The development of new tokens does not need any extensive smart contract programming. Rather, tokens can be created and managed via scripts that run-in user accounts on the blockchain. Toward this goal, programs and applications run as attachments to these transactions, and new assets are given a unique identifier.

Zilliqa. A public blockchain built on Ethereum which aims at true scalability with high throughput and low congestion. Its core feature is that it is a good foundation to build applications and networks that require high transaction throughput. Currently, it can handle 2,828 transactions per second. It uses practical Byzantine fault tolerance (pBFT) and Proof-of-Work (PoW) consensus mechanisms, where miners are only required to do consensus for five minutes out of every 1.5 hours.

Celo. Celo was designed to enable a new universe of financial solutions accessible for mobile users and takes a mobile-first approach that provides the opportunity to positively impact 6B+ smartphone owners globally, creating a global financial ecosystem where an end-user can onboard into the Celo ecosystem with just a mobile number. Celo uses a novel Proof-of-Stake (PoS) consensus protocol and a hyper-efficient light client. Celo's mobile-first approach to user-first decentralized finance (DeFi) means everyone has equal access to powerful financial tools and services – no matter who they

are or where they live – creating convenient, financial opportunities for anyone who is online and on their mobile phones.

2.3.6 Smart Contracts

NFT smart contracts are self-executing digital contracts that are stored on a blockchain, typically the Ethereum blockchain. They are responsible for managing the ownership and transfer of NFTs and enforcing the rules that govern their use.

Here is a general overview of how an NFT smart contract process works:

1. Creation: the creator of an NFT smart contract writes the code that defines the rules for the NFT, including the metadata, the ownership, and any royalties that should be paid to the creator when the NFT is sold.

2. Deployment: the smart contract is deployed to the blockchain, which means that it is added to the blockchain's immutable ledger and can be accessed by anyone with a compatible blockchain client.

3. Minting: the creator of the NFT uses the smart contract to mint a new NFT. This involves specifying the metadata for the NFT and assigning ownership to a specific Ethereum address. Once the NFT is minted, it is recorded on the blockchain as a unique asset that can be bought, sold, or traded.

4. Sale: the ownership of an NFT can be transferred from one address to another using the smart contract through a peer-to-peer transaction on a marketplace. This involves calling a specific function in the smart contract that transfers ownership and updates the ownership records on the blockchain.

5. Royalties: the smart contract can include provisions for royalties, which allow the original creator of the NFT to receive a percentage of the proceeds whenever the NFT is resold in the secondary market. These royalties are automatically enforced by the smart contract, ensuring that the creator receives their share of the proceeds every time the NFT changes hands.

6. Verification: The authenticity of the NFT can be verified through the blockchain, which records a unique digital signature for each NFT. This ensures that the NFT is unique and cannot be duplicated or counterfeited.

Case study: create and deploy a smart contract.

In order to interact with a smart contract on Ethereum, you will need to install a wallet and initialize an account with some Ether in it. Metamask is one of the most popular wallet apps. Then, you have to switch over from the Ethereum mainnet to the Rinkeby testnet to test. You have to initialize your project in your workspace and add the following dependencies:

- Hardhat, a development environment for Ethereum software
- OpenZeppelin, a library for secure smart contract development, with implementations of standards like ERC-20 and ERC-721.
- dotenv, a zero-dependency module that loads environment variables from a .env file into *process.env*.
- ethers.js, a library to interact with the Ethereum Blockchain and its ecosystem.
- node-fetch, to fetch API directly from native http without implementing *XMLHttpRequest*

Finally, to create the project you just need to initialize a Hardhat project. Subsequently is reported an example of smart contract called *NFT.sol*.

```solidity
pragma solidity ^0.8.0;

import "@openzeppelin/contracts/token/ERC721/ERC721.sol";
import "@openzeppelin/contracts/utils/Counters.sol";

contract NFT is ERC721 {
    using Counters for Counters.Counter;
    Counters.Counter private currentTokenId;

    constructor() ERC721("NFTTutorial", "NFT") {}

    function mintTo(address recipient)
        public
        returns (uint256)
    {
        currentTokenId.increment();
        uint256 newItemId = currentTokenId.current();
        _safeMint(recipient, newItemId);
        return newItemId;
    }
}
```

Figure 6: code of the definition of the smart contract "NFT.sol"

Above there is defined the version of the programming language Solidity we use, the import of the necessary contracts from OpenZeppelin, including ERC721 and counters.

Then there is the contract itself: it inherits from 721, declares a counter that we will use to keep track of the total tokens minted in the smart contract and defines the constructor.

Finally, the *mintTo()* function can be called by passing in a valid recipient address in order to mint a new NFT. It increments the *currentTokenId* counter, mints the next value of the counter to the recipient using *_safeMint*() private method, and returns the new token's ID to the caller.

Before deploying the smart contract, we have to compile it to make sure it is ready. We have to integrate our MetaMask account, since deploying the contract is going to cost ETH. We do this by adding our private key from MetaMask wallet and our Alchemy API key to the configuration *hardhat.config.js* of the smart contract, which will be like this.

```
require('dotenv').config();
require("@nomiclabs/hardhat-ethers");

const { ALCHEMY_KEY, ACCOUNT_PRIVATE_KEY } = process.env;

module.exports = {
   solidity: "0.8.0",
   defaultNetwork: "rinkeby",
   networks: {
    hardhat: {},
    rinkeby: {
      url: `https://eth-rinkeby.alchemyapi.io/v2/${ALCHEMY_KEY}`,
      accounts: [`0x${ACCOUNT_PRIVATE_KEY}`]
    },
    ethereum: {
      chainId: 1,
      url: `https://eth-mainnet.alchemyapi.io/v2/${ALCHEMY_KEY}`,
      accounts: [`0x${ACCOUNT_PRIVATE_KEY}`]
    },
  },
}
```

Figure 7: code of the configuration of the smart contract

In the first lines, there are some required imports from *dotenv* to use the variables defined earlier and from *hardhat-ethers* in order to later deploy our contract. The module configuration defines the Solidity version, the default network, and some

network configurations so that we can deploy the same code to Rinkeby testnet, Ethereum mainnet, or any other network later on.

We can then compile the contract with the command: *npx hardhat compile*.

In order to deploy the contract, we write a deploy script *deploy.js* in JavaScript and run it using HardHat.

```javascript
async function main() {

    const [deployer] = await ethers.getSigners();
    const NFT = await ethers.getContractFactory("NFT");
    const nft = await NFT.deploy();}

main()
.then(() => process.exit(0))
.catch((error) => {
    console.error(error);
    process.exit(1);
});
```

Figure 8: code of the script used to deploy the smart contract

This JavaScript function gets our account to verify that a minimum wallet balance is available, fetches the compiled NFT contract using *ethers.js* and deploys it.

Minting

In order to mint the NFT, the NFT contract can be connected to a website marketplace that provides a UI to mint a new token. This can be done with a script that utilizes the library *ethers.js* and *Hardhat* environment. We create a mint task to call our smart contract.

```javascript
const { task } = require("hardhat/config");
const { getContract } = require("./helpers");

task("mint", "Mints from the NFT contract")
.addParam("address", "The address to receive a token")
.setAction(async function (taskArguments, hre) {
    const contract = await getContract("NFT", hre);
    const transactionResponse = await contract.mintTo(taskArguments.address,
{
        gasLimit: 500_000,
    });
    console.log(`Transaction Hash: ${transactionResponse.hash}`);
});
```

Figure 9: code of the task that allows to mint an NFT

This task takes in an --address CLI flag, gets the contract we deployed and calls its *mintTo()* function with the address we will pass in the command line. We can do this by adding a new environment variable with the address of the contract we deployed and by

implementing a *getContract()* function in order to get an instance of the NFT contract. Finally, after importing the *mint.js* file to the *hardat.config.js* configuration file, we are able to mint token by calling our new mint task: *npx hardhat mint --address {address}.*

Now we have to add metadata (such as name, image, description and various traits) and a price to each minted token. The ERC-721 standard specification defines an extension called ERC721Metadata that defines a *tokenURI()* function that can take in a *_tokenID* field and outputs a link to the off-chain token metadata described above*.*

We can extend the *NFT.sol* contract to have a setter and getter for *baseURI* that can be used by OpenZeppelin's default *tokenURI()* function implementation, which for any of our minted *tokenIDs* will return the *baseTokenURI + tokenID*. Now we can upload some metadata and use *setBaseTokenURI()* function to set the metadata on tokens after the contract is deployed.

NFT metadata can be stored anywhere. It can be provided by a simple server you can create or on a cloud-based solution like AWS. These *centralized* options, however, are counterintuitive to the ethos of the Web3 movement and are therefore typically not preferred to more decentralized solutions like InterPlanetary File system (IPFS), Arweave or Pinata solution providers.

In this case we will rely on IPFS and Protocol Lab's "NFT storage" for metadata storage. We create two directories with images and metadata that will store all the JSON files uploaded as a compiled IPFS CAR (Content Addressable aRchives). We pack the files in an IPFS-compatible CAR, and upload them to "NFT Storage", so they will be ready to be set onto the smart contract. We can add two new Hardhat tasks: *setBaseTokenURI()* to set new values and *tokenURI()* to fetch token metadata.

We can use Etherscan to directly read and interact with a verified smart contract and share it with a community, by importing it to the hardhat configuration. This will add new *verify* task.

We can improve the smart contract by setting a maximum supply for the collection and adding a price to mint tokens from the contract.

```
    function mintTo(address recipient) public payable returns (uint256) {
      uint256 tokenId = currentTokenId.current();
      require(tokenId < TOTAL_SUPPLY, "Max supply reached");
      require(msg.value == MINT_PRICE, "Transaction value did not equal the
mint price");

      currentTokenId.increment();
      uint256 newItemId = currentTokenId.current();
      _safeMint(recipient, newItemId);
      return newItemId;
    }
```

Figure 10: code of the additional funcionalities of the mint task

For the former functionality, we just add a *require* statement to the *mintTo() function* that will cause it to not succeed in executing if the condition passed is false. For the latter, we add a new require line with the new constant MINT_PRICE.

The contract charges some ether to call the mintTo() function, but unfortunately that ether is now locked in the smart contract, so we have to implement a method to withdraw from it. Unfortunately, smart contract development in Solidity is prone to abuse from an exploit called the Reentrency Problem.

OpenZeppelin has implemented several solutions to protect against reentrancy exploits, include the *PullPayment* implementation, which can be imported in the NFT contract and exposes new functions that enable withdrawing from the contract.

Finally, OpenZeppelin provides a mechanism that makes the contract Ownable, meaning it creates access roles associated with contracts, in order to allow only the owner to withdraw from the smart contract for example.

2.4 NFT Marketplaces

An NFT marketplace is a website where users can trade non-fungible tokens. Some specialize in a certain niche, like a gaming sector or high-end art passionate, others embrace every type of NFT on the market. Some systems only focus on creating an environment where people may trade NFTs and then use them to display their treasures. Users can participate in various games or build NFTs using the ecosystem's tools. They will also get rewards by staking their NFTs on other NFT platform.

Interacting with an NFT marketplace requires a Web3 wallet, while users obviously all need the corresponding cryptocurrency to acquire or list NFTs. On the Ethereum

blockchain OpenSea is the biggest NFT marketplace, which currently support Solana and Polygon blockchain as well. SuperRare specializes in curated artworks, while LooksRare competes directly with OpenSea by adding their own LOOKS token. Some projects have their own internal NFT marketplace, like CryptoPunks and Axie Infinity. Marketplace's design can have a great impact on the market intelligence. For example, bidding costs, which depend on the marketplace's policies regarding transaction fees, bidding bots, or the user interface for placing bids. Indeed, market intelligence firms that provide tools which summarize sales and price data for different NFT collections do not take in account the differences in marketplace design, which may result in misleading comparisons of collections sold through different marketplaces. Moreover, most collections sell through one marketplace, making cross-marketplace comparisons difficult. Furthermore, marketplaces can differ on more than one dimension, making it difficult to isolate the effects of one design parameter. Each NFT marketplace platform is unique and provides consumers with several benefits. Marketplaces can differ by the blockchain they support, their fee structure, the types of NFTs they specialize in, and more. NFT marketplaces will sometimes support primary sales or mints, but they are also a major driver of secondary sales.

Wallets. In order to buy an NFT, you'll need a crypto wallet and cryptocurrency, or, in some cases, just a credit or debit card. A crypto wallet is a program that stores your NFTs and cryptocurrency. Not all wallets store NFTs, and not all wallets support blockchains, so make sure your wallet is compatible. A few of the most popular wallets are:

- Metamask. One of the most widely used Ethereum wallets, with over 30 million monthly active users. [32] Its user-friendly interface provides quick and easy access to many tokens and decentralized apps within the Ethereum Network and other compatible blockchain solutions. It supports more than 700,000 assets.
- Coinbase. Separated from the main Coinbase Exchange platform, this wallet connects to the most major bank accounts, and the user interface is designed to

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[32] Claimed by ConsenSys, the founder of Metamask.

be intuitive and easy to navigate. It can store popular coins and more than 5,500 supported digital assets.

- Crypto.com DeFi Wallet. Wallet created by Crypto.com exchange, specifically tailored for decentralized Finance (DeFi), the sector of crypto focused on lending, saving and other financial products that don't rely on a central broker. It supports more than 1,000 assets.

- Exodus. A wallet with an easy setup process that supports 291 cryptocurrencies, with a good speed of transactions, easy to use and many functionalities.

- Phantom. A popular wallet for Solana-based decentralized applications and NFTs.

NFT transactions happen using cryptocurrency, although many NFTs marketplaces allow to buy NFTs with a credit or debit card.

Purchase methods.[33] There are two main ways to buy NFTs: on independent project websites, or on NFT marketplaces. I will focus on the latter. Most NFT marketplaces are peer-to-peer. They require sellers to list an item for a fixed price but also enable participants to place bids that are typically lower than listing prices. Sellers can choose to accept the bid or wait for someone to purchase the item for the listing price or make another bid. On one extreme, marketplaces can ban bidding and only allow sellers to sell NFTs through fixed price listings. Alternatively, marketplaces can choose to bear the transaction costs of making bids, referred to as gas fees on the Ethereum blockchain, and build infrastructure to store bids "off-chain" to eliminate transaction fees. In this way, they can incentivize the development of bidding bots or create user interfaces that facilitate bid placement. For example, using OpenSea, you can buy items listed for sale instantly, bid in auctions, or make offers on any NFTs. OpenSea allows users to place bids on as many listings as possible with no fee, whereas the Larva Labs marketplace requires that users pay a (gas) fee to bid. OpenSea has encouraged third-party bots, while Axie Infinity or NBA Top Shot discouraged bots and restricted associated accounts. The types of purchase[34] are the following:

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[33] Pavel Kireyev, 2022 - "NFT Marketplace Design and Market Intelligence"
[34] OpenSea, 2022 - "How to buy NFT" retrieved on :[https://opensea.io/learn/how-to-buy-nft]

- Buy now. The buyer can immediately purchase the digital piece for a fixed price. This option does not usually disappear in NFT marketplaces after the first bid is placed, unlike platforms like eBay. NFTs can be purchased any time during the sale period and without any additional involvement from the seller. This is the simplest method, similar to other e-commerce websites.

- Place offer. Anyone can make an offer on an item, even if it is not listed for sale. Anyone can also make an offer on a listed item, if he or she wants to offer less than its listed sale price. The offer can be later accepted or rejected by the seller, who can wait for a higher bid.

- Auctions. When an NFT is up for auction, potential buyers can bid on the item. The NFT will either go to the highest bidder, or the seller can choose to accept any offer during the auction. This method is not very prevalent in NFT marketplaces.

- Buy now with credit card. This can happen through platforms like MoonPay, Diamond Wallet, Simplex, and Wert which allow to convert fiat currency to cryptocurrency, which is used to purchase NFTs. A credit card processing fee will apply to all credit card purchases (if you are using Ether, gas fees will apply as well). To use a credit card to purchase NFTs, you must first complete an identity verification on the platform with valid identity document, such as a passport or a driving license.

2.4.1 Governance

Governance is an important topic regarding blockchain consortia. Governance can be defined as the legal and factual regulatory framework for the management and supervision of a project. In NFT marketplaces, it refers to the framework, which is required to be set up in the given use case, so the focus should be the governance in blockchain, which is one of the fundamental aspects of blockchain design. To ensure long-term success, it is important to not only incorporate the necessary technical framework, but also a governance structure. Weill presented an IT-governance framework based on three dimensions: decision rights, accountability, and incentives.

In a traditional company, the decision-making process often is not transparent, due to the lack of structures that allow it, and often are only inherent to a small circle of people, which may or may not be governed by an additional board. With the introduction of blockchain companies, this concept of decision-making will change: decision rights switch from the concept of who can decide on a company's activities to who has the responsibility and authority to provide doings on a platform. However, since not all participants have perfectly aligned interests, conflicts could arise. Accountability is important to get the trust of participants, but this should be guaranteed by the blockchain who can provide fraud-proof working environment. Finally, incentives can be carried out in many ways, for example by linking the achievement of certain targets to a payout.

In NFT marketplace, governance has to balance suppliers, buyers, and neutral parties interacting with the marketplace. Suppliers are a core component of the marketplace; thus, they must be incentivized to join by giving them the opportunity to forge decisions with voting rights. Vice-versa, buyers might insist on cutting rights or imposing conditions on their suppliers when it suits their preferences as long as an outside option exists. However, supplier-dominated governance where profit generation influences decision power too much can lead to a platform oligopoly. If firms with a majority of voting power protect their rights by increasing obstacles for market entry of small competitors, market concentration could arise. For this reason, democratic decisions concerning the structure of the marketplace must be avoided for the sake of the structural integrity of an open marketplace. In contrast, the governance of this marketplace should concentrate on avoiding situations of any type of lock-in. [35]

While the blockchain is decentralized, the major NFT marketplaces like OpenSea, Coinbase, and Axie for example, are centralized. Indeed, many projects direct members to NFT marketplaces for secondary sales, which happen almost exclusively on marketplaces. Using these major marketplaces may be the best solution to spread the own popularity, but the need for more decentralized services and platforms, such as

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[35] "Governance in Decentralized IoT Marketplaces" – Medium.com, 2021
https://philippsandner.medium.com/governance-in-decentralized-iot-marketplaces-8061be50d1c9

community-hosted marketplaces, is clear, in order to make a better user experience and eliminate the costs that will lead to higher trust. [36]

Some NFT marketplaces are using the decentralized autonomous organization (DAO) concept. A Decentralized Autonomous Organization (DAO) is an organization where the rules of operation and organizational logic are encoded in the framework and users have the complete authority to participate in voting for decisions in the NFT marketplace. Collector DAOs allow multiple individuals to own a fragment of an NFT, this gives smaller NFT trades an opportunity to join more expensive projects. DAOs also have the potential ability to help emerging NFT creators foster a community. These platforms place a greater emphasis on the demands of the user and power future-oriented ideas like Metaverse marketplaces DAOs provides transparency, staking and governance power in the NFT market through distributed decision-making.

These are the main differences between centralized marketplaces and decentralized platforms. [37]

Centralized Marketplaces	Decentralized Marketplaces
The platform owner is the ultimate authority and is responsible for all platform-related decisions	The community makes every decision on the platform
The marketplace owner can change the platform's functionality or add new features	Through voting, marketplace users can participate in changing how some features or functions work
New changes and implementation may take time since humans back the traditional NFT platform	Users can implement changes immediately because smart contracts support the functions
A governing entity can shut down the marketplace on command	Only a majority of votes may bring down the marketplace
The functionalities are not fully comprehensible	Users will be able to understand the marketplace's full functionality

Table 3: advantages and disadvantages of centralized and decentralized marketplaces

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[36] "NFTs Martkeplaces Are Centralized, and It's a Real Problem" – nftnow.com
[37] "Developing DAO-enabled NFT Marketplace" – blockchain.oodles.io, 2022
https://blockchain.oodles.io/blog/develop-dao-enabled-nft/

The main advantage of a DAO is the already mentioned decentralization, which gives traders control over their platform-related actions and eliminates the influence of a centralized authority. Members have the power through a voting system to perform auditing tasks, such as altering policies, features, upcoming upgrades or even the projects to raise like in a crowdfunding platform.

DAOs operate using smart contracts to automatically execute a command whenever a set of conditions are met. The rules of a DAO are stored on an open-sourced blockchain, meaning anyone can look at their code and transaction records. A central entity does not direct the decisions in a DAO but through proposals shared with the project community, who then vote on them. DAO functions similarly to a corporate, except it works without a hierarchical structure; it attempts to provide a new, democratic process through decentralized governance. Unlike a traditional organization, members of a DAO are not bound by any formal contract. Instead, they are bound together by a common goal or incentives written into their rules.

The users who are eligible to group may be included in the following groups: the early users of the marketplace, the community contributors who have engaged meaningful conversations on Discord server, ecosystem contributors who have contributed to the public goods infrastructure that keeps the blockchain running. Then these people can claim their voting power on the website, or delegate someone else.

This system can be gained through the introduction of a proprietary token, which can give to the owner the vote to right. Often, NFT marketplaces make an airdrop, a marketing strategy that involves sending coins or tokens to wallet addresses. Small amount of the new virtual currency is sent to the wallets of active members of the blockchain community for free or in return for a small service, such as retweeting a post sent by the company issuing currency. The goal of this event is to promote awareness and circulation of a new token and introduce a DAO. There are many types of airdrops: standard airdrop, where participants simply have to express their interest; bounty airdrop, that occur when users perform certain tasks, like recruiting other users; holder airdrop, that occur automatically based on who is holding already a certain amount of

tokens; exclusive airdrop, where specific people are selected; raffle airdrop, where raffle ticket are distributed.[38]

One of the most popular NFT marketplace that have adopted a decentralized-autonomous organization system is Mintable, who combines both DAO and NFT trading by giving traders who owns ERC-721 NFTs voting right. Another example is Flamingo, where it is up to the community members to approve any NFT developers' proposals to list their NFTs on this platform. Additionally, this platform makes it easy to fractionalize NFTs and continue trading them.

2.4.2 Transaction costs

There are many fees that you have to pay when you mint or buy an NFT.

- Gas fee.[39] It is a blockchain transaction fee that's paid to validators for their services to keep the blockchain secure. Without gas fees, there would be little incentive for validators to stake their ETH and keep network secure. All blockchain transaction incur a gas fee including minting, buying, selling and transferring NFTs and cryptocurrency. Most commonly, NFT gas fees are mentioned when talking about the Ethereum blockchain, which currently has some of the most expensive gas fees, ranging from 5$ USD to 500$ USD depending on the type of transaction and the demand on the blockchain. Indeed, gas fee is the price you pay to create, buy, send, and sell NFTs on the Ethereum blockchain. This price depends by the supply and demand between the blockchain's miners. The total transaction fee is equal to the gas limit times the gas price at that moment.

$$Total\ transaction\ fee = Gas\ Limit * Gas\ Price\ per\ Unit$$

The exact formula for Ethereum gas fee equals:

$$Gas\ unit\ (limit) * (Base\ fee + Tip)$$

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[38] "Airdrop Cryptocurrency" – Jake Frankenfield, 2022
https://www.investopedia.com/terms/a/airdrop-cryptocurrency.asp
[39] "NFT Gas Fees Explained" – Alex Gomez, 2022
https://cyberscrilla.com/nft-gas-fees-explained/#:~:text=Most%20commonly%2C%20NFT%20gas%20fees,the%20demand%20on%20the%20blockckchain.

If there is high demand for transactions, this requires more miners to complete complicated algorithms creating more work and energy consumption. If the gas price does not meet the threshold power, miners can choose to not process the transaction. Every transaction on the Ethereum network costs gas. Gas on the Ethereum network has been assigned a market price based on the demand for resources in the network at a particular moment in time. This is done to ensure that there is efficiency in the network and there is the best use of computational power. The main criteria for gas expenses will depend upon the size of the contract you are trying to execute as well as the speed at which you want that transaction to be completed.

However, there is a gas fee limit which refers to the maximum amount of gas someone is willing to spend on a transaction. A higher gas limit means that a transaction has priority over other people who submitted a lower gas limit. When gas prices are high it becomes difficult for creators to mint and list their work, since costs may be much higher than the actual cost of the assets they are selling. Also, buyers have to pay for gas whenever they place an order or cancel one.

Since not everyone is willing or able to pay for gas, some NFT marketplaces have implemented gasless minting, which allows creators to deploy NFTs onto a platform without paying for the blockchain gas fee up-front. Rather, the fee is deducted at the time of sale and enables creators to mint their NFTs for free. This is achieved by not publishing any data to the blockchain until an item is sold. Marketplaces that offer gasless minting for NFTs are Opensea, Mintable and Rarible.

- Commission fee. Fee charged by marketplace for providing the technological gateway for helping artists to set up their NFT and facilitating the trading of NFTs. It may vary from one marketplace to other, and it will be applicable on all the sales transactions happening in there. It typically ranges between 0% and 15% of the transaction. OpenSea, the largest NFT marketplace, charges 2.5% per transaction.

- Royalty Fee. NFT royalties are payouts that compensate the original creator every time a secondary sale of their digital asset occurs. The royalty percentage is set by the creator at the time of minting, commonly around 3% and 10%, but it can be set as optional as well. This percentage is taken from the sale price and sent to the creator. These royalties are coded into the smart contract of the blockchain and vary by an NFT to the other. Each time a secondary sale happens, the smart contract ensures that the terms of the NFT are fulfilled. The royalty is based on NFT's sales price, which may be different for each sale. Therefore, the creator may earn a different number of subsequent sales even though the royalty percentage remains the same.

In this way, artists have the benefit of getting returns for something they produced once on a recurring basis. A lot of digital artists and content creators are motivated by this and hence are rushing to join the NFT ecosystem. Traditionally after the first sale, the artist or creator did not have any way to track the subsequent transactions of their work. Once they had sold their work that's all their earnings would be from that piece of work. NFTs have brought in the opportunities to change this completely, so artists can have their fair share of the sales from their creations for perpetuity.

While not all marketplaces are geared towards offering royalties, ones like Rarible let you enter royalties when minting an NFT. This fee is not mandatory to be applied and thus is subject of interest for the owner/seller of the asset. Hence, this fee also varies depending on the seller or the art.

Some NFT marketplaces, including sudoswap, LooksRare and X2Y2, have either eliminated an NFT royalties' system or taken steps to dramatically curb it. This trend began in the summer of 2022, when there was a move to make royalties optional, with marketplaces creating a type of tipping system. In this way buyers are allowed to choose the amount of royalties they would like to contribute to projects. This had a backlash against marketplaces seeking to reduce or eliminate royalties and many digital artists have boycotted exchanges that no longer support NFT royalties for their digital assets. Due to this, many NFT marketplaces have restored royalties.

Instead, OpenSea has recently introduced a royalty enforcement tool on

November 8, 2022. Its purpose is to make NFT royalties enforceable on its blockchain. When digital artists create assets with this tool, these works cannot be sold on the NFT market through exchanges that do not enforce the payment of NFT royalties.

2.4.3 Token

A token is a digital object that contains information about the identity of the principal making the request and what kind of access they are authorized for. In our case, crypto tokens are units of value that blockchain-based organizations or projects develop on top of existing blockchain networks. While they often share deep compatibility with the cryptocurrencies of that network, they are a wholly different digital asset class.

Cryptocurrencies are the native asset of a specific blockchain protocol, whereas tokens are created by platforms that build on top of these blockchains. For example, the Ethereum blockchain's native token is ether (ETH) but crypto tokens are built using Ethereum Tether, Chainlink, Shiba and CryptoKitties. Crypto coins have their blockchain, unlike cryptocurrency tokens. Creating the former is more difficult than the latter. Typically, crypto tokens are:

- programmable, meaning that these digital assets run on smart contracts.
- permissionless, since someone does not need special credentials to participate in the system.
- trustless, since there is no central authority in the system.
- transparent, since anyone can view and verify the protocol rules and transactions.

Crypto token prices are subject to significant fluctuations because of the dynamic economic environment. There are six types of crypto tokens: transactional, governance, utility, security, platform, and non-fungible tokens.

- Platform tokens. These tokens support a decentralized application (dApp) on a blockchain. They benefit from the blockchains they build upon, gaining enhanced security and the ability to support transactional activity. They can run many use

cases, from serving gaming and digital collectibles platforms to global advertising and marketplaces industries.

- Security tokens. The objective of security tokens is to be the crypto equivalent of conventional financial securities like stocks, bonds, etc. They represent ownership in these traditional financial assets. Moreover, they serve as direct, on-chain representations of real-world securities or tokens that are on-chain instruments serving a similar purpose for blockchain projects and digital assets.

- Transactional tokens. They are used to transact, so they serve as units of accounts and are exchanged for goods and services. They often function like traditional currencies but may provide additional benefits.

- Utility tokens. These tokens allow users to access a blockchain-based service or product. They can be used to pay for services within the ecosystem. For example, *DAI* is integrated into Axie Infinity, a digital-pet universe with a player-owned economy, providing players with a stable in-game currency.

- Governance tokens. They enable token holders to vote on particular things, for example, the future of an application or protocol. On-chain governance allows all stakeholders to collaborate, debate and vote on how to manage a system. For example, in the Maker Protocol, the governance is MKR.

2.4.4 NFT marketplaces cases

In this paragraph, the most popular NFT marketplaces are described singularly. It was chosen to analyze the platforms that had the biggest impact on the market, so factors to be considered in the selection were the amount of the volume sales, the users and the growing of their popularity and the features that they implemented.

OpenSea

The most popular marketplace is OpenSea, that with its volume sales of over $32,49 billion USD has taken alone the 63% of the volume sales of NFT marketplaces analyzed. The American company founded in 2017 by Devin Finzer and Alex Atallah, is platform that offers all categories of NFTs and cross-blockchain support. It gained its popularity building a supply and demand by looking for partnerships in Discord to discover new NFT projects and implemented robust filtering and sorting features to allow easy discovery

for NFTs. In this way, it out hustled it close competitor at the time, Rare Bits, and attracted most of the trading volume. This led to partnership with Axies, Decentraland, the Major League Baseball and the football club Bayern Munich. Further they implemented user-centric features that enabled easy onboarding for suppliers, like permissionless listing of NFTs, which eliminated the need for any approvals or complicated onboarding and created for first a way to pass the cost of minting new NFTs on Ethereum. Both these features significantly reduced the barrier to onboarding of budding artists/projects, which greatly contributed to the extensive inventory of NFTs on the platform.[40]

In order to contrast the biggest problem of NFT, the prohibitively high gas costs, OpenSea did not have any control over the gas costs of the underlying Ethereum network but implemented multiple features to at least mitigate these costs. They enabled auctions to happen off-chain, so that gas is only used once during the final sale, allowed auction prices to be lowered off-chain so that price change does not require gas every time, introduced "lazy minting" so that artists can mint NFTs for free and gas is paid by the buyer when they buy the NFT for the first time and integrated with Polygon, a blockchain network that interacts with Ethereum but has lower fees. Finally, they allowed to pay NFT with other crypto than ETH, especially stable coins like Dai and USDC. Their best choice was their conviction in the new standard ERC-721, since before that each project had to create its own marketplace, and this made them survive to the crypto winter of 2018. When the crypto markets were going down and not many projects were able to survive, OpenSea ran a lean team of just seven employees, kept charging transaction fees to keep the company float, and kept building. More recently, they had to reimburse some users that sold some high-value NFTs at a lower price, had to freeze stolen NFTs and block NFTs originally minted on its platform from being resold on secondary marketplaces that did not enforce full creator royalties, like Blur.

On February 2023, OpenSea, to contrast Blur, has changed it policies by charging 0% marketplace fees, and default all collections without on-chain royalty enforcement to

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[40] Mirror team (2022) – "How did OpenSea become the most popular NFT marketplace" retrieved on 20/12/2022 at :[https://mirror.xyz/supreet.eth/5dRdAbJqGq3RoHvPG0DjzoANqw0xwXRlzDP8gZUoG7k]

optional creator royalties starting at 0.5%. The marketplace has also adjusted its blocklist of other marketplaces that don't honor full royalty payments to creators, allowing sales on NFT marketplaces with these policies, including Blur, no longer forcing creators to choose between the two platforms in order to earn full royalties on its collections.

Axie Marketplace

Axie Marketplace is the marketplace of Axie Infinity, the most popular and successful NFT-based Play-To-Earn (P2E) crypto game launched in March 2018 that use blockchain to turn in-game items and currencies into tradable assets with real-world value. In the game, players own all their Axies as NFTs on Ethereum, allowing Axies to be sold to other players. The game is a turn-based card game and reward players with in-game items when they win battles. Smooth Love Potion (SLP) is the game's cryptocurrency required for breeding Axie pets, while Axie Shards (AXS) are the game's governance tokens that allow players to vote on new developments. The game saw a sudden popularity in June 2021, and several players earned enough money to pay their household expenses. It has an all-time volume sale of $4,25 billion USD, which is the 8,5% of total volume sales of the report analyzed.

CryptoPunks

CryptoPunks is a collection on the Ethereum blockchain launched in June 2017 by Larva Labs studio, consisted by Matt Hall and John Watkinson. There are 10.000 tokens in total on ERC-721 and due to their rarity and exclusivity, they sell for high prices on the open market. The hype around these have raised on with a small but passionate community, until 2021 when they gain popularity that rose its prices thanks to the rise of prices cryptocurrencies and the popularity of NBA Top Shot. On 2022 all of the CryptoPunks IP was acquired by Yuga Labs, which then owned their website. CryptoPunks has an all-time volume sale of over $3 billion USD, which is the 6% of the total volume sales of the NFT marketplaces analyzed.

Magic Eden

Magic Eden, which was launched in September 2021, is the largest NFT marketplace on the Solana blockchain. The platform includes several user-friendly features, like seamless interface with categories, many filters, and a unique launchpad for minting, that have been attracting a considerable number of traders. Moreover, you can purchase Magic Tickets to access to the Magic Eden Decentralized Autonomous Organization (DAO) on Discord channel, where users can vote on future policies. To promote the adoption of Solana NFTs, Magic Eden created a unique launchpad that helps creators to mint NFT by taking care of the technical side and kick-start their projects, but only 5% of the applications are accepted. After a few months Magic Eden became so popular that in May 2022 it surpassed its competitor OpenSea in daily trading. Magic Eden has an all-time volume sale of over $2 billions USD, which is the 4% of the volume sales of the NFT marketplaces analyzed.

Blur

Launched on October 2022, Blur is an NFT marketplace and aggregator where users can compare and sell NFTs across marketplaces, manage portfolios with advanced analytics, as well as buy NFTs. It states that it is the marketplace for professional traders where users can sweep and snipe NFTs faster than on other platforms and it is ten times faster than the aggregator rival Gem. Its popularity can be partly attributed to the BLUR governance token airdrop to NFT traders who earned rewards through the marketplace. The platform provides users good tools, such as a seamless user interface, "floor sweeping" across marketplaces, fast "snipe reveals" and improved liquidity. On top of that, Blur offers zero platform fees and optional royalties, making it a cheaper alternative to its competitors. Blur's rise has made OpenSea, sudoswap and X2Y2 change its creator royalties and platform fees to stay competitive, since it allows its users to pay optional royalties back to creators. Blur has an all-time volume sale of $1,7 billion USD, which is the 3,4% of the volume sales of the marketplaces analyzed in the report. However, on February the sales' data tracker CryptoSlam decided to remove hundreds of millions of dollars' worth of Blur trades from its data due to "market manipulation" and now it filters it through un updated algorithm that excludes "suspicious" sales, in

which users farm points to earn tokens by buying their own listings using a different wallet.[41]

Sudoswap

Sudoswap, which launched in May 2022, is crypto's first NFT automated market maker. Automated market makers (AMMs) allow digital assets to be traded in a permissionless and automatic way by using liquidity pools that use algorithms rather than a traditional market of buyers and sellers. AMM users supply liquidity pools with crypto tokens, whose prices are determined by a constant mathematical formula.

These platforms allow users to exchange assets with confidence via user-funded liquidity pools, but users of sudoswap may trade between NFTs and ETH rather than two fungible tokens. Sudoswap's pools, unlike OpenSea, are totally decentralized and sponsored entirely by their users. However, this does not imply that trading is free; the trading pool's designer establishes a swap cost of a few percent of each successful NFT buy or sell. The lower the swap costs for a particular pool, the more incentive users have to trade through it. Sudoswap also allows NFT owners to sell their assets instantaneously without having to wait for a buyer, enhancing liquidity and efficiency in the NFT market. The most unique aspect of sudoswap, however, is how it regulates the value of the NFTs exchanged through its pools. The platform uses bonding curves to automatically raise and reduce the bid and ask on each collection based on the number of NFTs purchased or sold. For example, if a user sells an NFT into a pool, boosting supply, the buy price falls significantly.

Other marketplaces

Blur is hardly the only company competing against OpenSea. The landscape has become much more diverse over the last year as new players enter the market. The increased competition has led to existing marketplaces having to try new things beyond the realm of royalties and fees. LooksRare is due to roll out its own revamped rewards system. Rarible meanwhile is pushing for more community marketplaces — branded,

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[41] Callan Quinn, Forbes (2023) – "What Blur's Success Reveals About NFT Marketplaces"

community-run platforms geared towards specific collections — to give them more control over the sale of their own collections.

Volume sales are a good index to describe the popularity of a market, however, some marketplaces such as Blur and LooksRare have been accused of activities of wash trading.

LooksRare

The analytics portal CryptoSlam says that the vast majority of the sales of the NFT marketplace LooksRare are illegitimate trades meant to manipulate the token rewards model. The analytics estimates that LooksRare has generated more than $8.3 billion worth of wash trades out of $9.5 billion in total Ethereum, making up the vast majority of its sales volume to date. Most of the wash trading comes from royalty-free collections, which means that sellers don't have to pay the creators a secondary sale fee. LooksRare offers token rewards for users who buy and sell NFTs on the site, offering them a percentage of the day's total sales via the site's own LOOKS token. Users can game the system by selling NFTs back and forth between their own wallets, with the aim of earning more in LOOKS rewards than they would spend on LooksRare's 2% marketplace fee. CryptoSlam removed wash trading data from its total sales metric and has implemented a tracker for each NFT collection that shows the total amount of wash trading to date. For this reason, the volume sales regarding the platform have been collected from the website Dune, which excludes all the volume sales that are considered being part of this wash trading activity.

3 Methodology

3.1 Investigation Strategy and Objective of the Research

In the previous chapter a comprehensive analysis of the literature has been conducted. The previous analysis highlights the existence of several scientific papers that are dedicated to the technical aspects of NFT and the marketplaces: from the description of the blockchain mechanism, to the programmability features enabled by smart contracts.

From the previous chapter, it emerges also that NFT have gained a lot of interest but then their popularity decreased a lot during the last year. Indeed, NFTs are the subject of much research worldwide, both for academic studies, but also for governmental research, which have to think about the regulation for them. In this regard, the level of knowledge in society about NFTs is increasing and companies and governments have realized their true potential, especially in the eventual metaverse.

This is evidenced by the fact that major technology solution providers are investing heavily in this field and numerous NFT projects worldwide have received remarkable investments in every sector: from the fashion luxury to the videogames.

The disruptive potential of NFTs in several areas has been widely recognized, however the technology behind these is still in the early stages when considering the adoption rate. There are still important unsolved aspects regarding the current limitations that these platforms present and there is still uncertainty about the best choices to be made from a technical point of view and aspects like the governance.

In this regard, the analysis of scientific papers in the literature review has identified DAO and fully on-chain marketplaces as possible leaders in the evolution of technologies and therefore as strategic players to be studied with this regard to the implementation of blockchain technology in business.

In particular, decentralized marketplaces that save all data on-chain can be considered an important means through which it is possible to draw indications on the directions of the development of NFT marketplaces. A similar reasoning can be applied to Layer 2

solutions which can make the transactions faster and less expensive at the same time. For these reasons, literature shows that these cannot be excluded from the analysis.

Finally, the literature so far includes very few empirical studies conducted on companies that make direct comparison between the NFT marketplaces in their business models and even fewer have analyzed in reality what technical choices have been taken by them (concerning platform, data saved, and protocol used, for example).

Given the importance of this issue and the description just described, this study aims to:

Describe the current ecosystem of marketplaces whose business model is based on the trade of non-fungible tokens.

To do this, an empirical analysis has been conducted on NFT marketplaces selling these digital items globally. The level of investment raised has been recorded and used as an indicator of investors' interest, to make assumptions about the directives of development of NFTs and their future use in business applications.

3.1.1 Research Question

The investigation strategy described above, ultimately aims to answer the following research questions:

What are the latest trends and the future directions of development in the NFT marketplaces? What will be the key to success in the NFT ecosystem?

3.2 Research Methodology

The literature review has highlighted the gaps in existing knowledge about NFT technology when considering their applications in business environment. In particular, these is a lack of concrete frameworks applicable to the business models of NFT marketplaces, there are no in-depth investigations regarding the role that tokens play in these business models and which major incentives Blockchain and DLT technology is able to offer at corporate level.

In addition, the literature analysis has indicated that the best strategy to indicate what might be the most successful technical and business choices in the future of this sector is to conduct an empirical investigation of NFT marketplaces and their funding.

In this chapter, it has been described the methodology that has been followed to carry out this investigation, which has been divided into two main sections:

1. Database: how the list of NFT marketplaces has been generated and how additional data has been collected to create the Database of NFT marketplaces.
2. Empirical analysis: how the NFT marketplaces ecosystem has been empirically analyzed to find pertinent models and frameworks and spot new patterns.

3.2.1 Data collection and categorization of variables in the Database

The phase of data collection on the NFT marketplaces that are included in the Database has been realized in collaboration with the "Blockchain and Distributed Ledger Observatory" of Politecnico di Milano. The Observatory provided an important support in the following phase of data categorization, which will be tackled later in this section.

The NFT marketplace sample has been extracted from Dappradar.com, using the NFT section, and Dune.com. Dappradar is an online website that collects data on ecosystem of international companies, with a particular focus on the NFT market and this made it a particularly suitable source, with others, for the extraction of raw data for this research. Dune is a data platform widely used by crypto-asset investors and analysts to help them research individual projects, certain sectors (for example non-fungible tokens).

This census has been made considering only the marketplaces that had a monthly volume that exceeds a certain threshold, an all-time volume that exceeds another threshold, and a minimum significant value of active traders. Since the extraction has been performed in October 2022, this implies that the filtering criteria are the following:

- Trading monthly volume: over $0 USD
- Trading all-time volume: over $5.000 USD
- Active traders: over 50 users

A total of 100 marketplaces have been extracted. The variables provided by Dappradar that have been held for the census were the following:

- Marketplace name
- Marketplace website
- Marketplace description
- Trading monthly volume
- Trading all-time volume
- All-time traders
- Blockchains supported

However, Dappradar is not exclusively focused on NFT marketplaces, so the data extracted from there did not include specific information needed for the analysis. It has been considerate appropriate to use the combination of this source with selected supplementary data sources, like the official document of the marketplace or data platforms such as Dune, to obtain a more detailed overview of the subject.

Therefore, it has been chosen to integrate the above-mentioned information with additional data from other sources, specifically concerning NFT marketplaces, such as the data analytics Crypstoslam.

3.2.2 Collection and categorization of information

The qualitative data collection was made through a census, elaborated on an Excel file where all the data were gained online or through interviews. These are the definitions of each variable of the document, with all the possible values described precisely in order to avoid any ambiguity. The variables collected for each NFT marketplaces have been the following:

- Marketplace
- Blockchain supported
- Standard
- Governance
- Data storage

- Royalty Fee
- Commission Fee
- Gas Fee
- Volume (Month)
- Volume (All time)
- Traders (All time)
- Token
- Minting
- Purchase method
- Foundation Year
- Website
- Brief description
- Country
- Continent
- Type

Marketplace. Name of the NFT marketplace, a platform where you can whether buy or sell any non-fungible tokens and discover digital items. These platforms allow people to store and display their NFTs, and some of them allow to mint NFTs as well. In exchange for a fee, the NFT marketplace will typically handle the transfer of an NFT from one party to the other.

Blockchain. The blockchain network(s) on which the NFT marketplace is based on.

- Ethereum, the most popular decentralized, open-source blockchain with smart contract functionality.
- BNB Chain, the blockchain of the Chinese trading platform Binance, with fast and cheap transactions and compatibility with Ethereum Virtual Machine (EVM)
- Polygon, a decentralized Ethereum scaling platform that enables developers to build scalable user-friendly dApps with low transaction fees.

- Solana, the fastest blockchain with high scalability that ensures low cost of transaction (less than 0.01$)

- Theta, blockchain infrastructure for video, media and entertainment

- Flow, blockchain with Proof-of-Stake consensus mechanism that makes it scalable and carbon-less

- Waves, a blockchain designed to enable users to create and launch custom crypto tokens

- Zilliqa, a blockchain that enables to create user-friendly dApps easily

- Immutable X, a layer-2 scaling solution for NFT on Ethereum collaborating with GameStop

- Worldwide Asset eXchange, a carbon neutral blockchain that runs on a Proof of Stake system

- EOS.IO a blockchain used to develop, host and execute dApps

- Ronin, an Ethereum-linked sidechain built specifically for games

- Cardano, the seventh largest blockchain in the world

- Wax, a sidechain of EOS blockchain, born with the intent to create, buy, sell and trade NFTs in a convenient and secure way

- Celo, a blockchain designed to be accessible for mobile users

Standard. The standard protocol used to mint tokens on the blockchain.

- ERC-20, a standard to build fungible tokens on the Ethereum blockchain

- ERC-721, a standard to build non-fungible tokens on the Ethereum blockchain

- ERC-1155, a standard interface for contracts that manage multiple token types. A single deployed contract may include any combination of fungible tokens, non-fungible tokens or other configurations (e.g. semi-fungible tokens).[42]

- ERC-998, a standard that provide a template by which NFTs can own both non-fungible and fungible assets.

- BEP-20, an extension of ERC-20 used by BNB chain

- BEP-721, an extension of ERC-721 used by BNB chain

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[42] "ERC-1155" – Ethereum.org, 2018
https://eips.ethereum.org/EIPS/eip-1155#simple-summary

- BEP-1155, an extension of ERC-1155 used by BNB chain
- SIP-009, a standard protocol used by Stack blockchain

Governance. Blockchain governance is the means of achieving the direction, control, and coordination of stakeholders within the context of a given blockchain project to which they jointly contribute. In an NFT marketplace, the governance can be:

- Decentralized, if the decisions about the evolution of the blockchain project are discussed and taken based on the will of all the stakeholders, in a DAO. The participation mechanism of the users in NFT marketplaces can be given through a governance token, which gives the right to vote to the owner.
- Centralized, if the decisions about the evolution of the blockchain project depends exclusively on the will of the owners of the platform.

Storage data. The method with which the data of the transactions are saved. Metadata can be baked directly into the smart contract representing the tokens or hosted separately. Blockchain transactions are made secure by a consensus mechanism system, which means transactions need to be approved by the network.

- On-chain, if every step linked to a transaction occurs on the blockchain, and the blockchain status is modified to reflect the occurrence and validity of the transaction. All the metadata's of NFT are saved on the smart contract.
- Off-chain, if the values linked to a transaction are saved outside of the blockchain, in a centralized database.
- On-chain/Off-chain, if many of the values linked to a transaction are saved on the blockchain and others are saved outside of it.

Royalty Fee. The percentage that is given to the creator of the NFT once a subsequent sale is executed, allowing him to benefit from secondary sales. This fee can be chosen by the artist during the minting of the NFT, by the marketplace, or buy the buyer(facultative). Its thresholds are commonly set around 3% and 10% of the transaction. The value is defined in US dollars.

Commission Fee. The percentage that the NFT Marketplace charge when an NFT is sold in its platform. It typically ranges between 0% and 15% of the transaction. The value is defined in US dollars.

Volume (Month). Sales transactions volume of NFTs in the marketplace within the month. The value is defined in US dollars.

Volume (Total). Sales volume of NFTs in the marketplace since its launch. The value is defined in US dollars.

Traders (Total). Number of active traders within the platform since its launch.

Token. Proprietary token of the marketplace, which is widespread through an airdrop and can have many functionalities, such as governance token or utility token.

Minting. Possibility of the users to mint NFT directly through the NFT marketplace.

- Yes, if the marketplace allows its users to mint an NFT on their platform
- No, otherwise

Purchase method. The modalities with which a user can buy an NFT in the marketplace.

- Buy Now: the buyer can purchase the digital item by clicking on a button "Buy now" for a fixed price proposed by the seller
- Bid: make an offer on an item, which can be later accepted or rejected by the seller
- Auction: the digital item will either go to the highest bidder, or the seller can choose to accept any offer during auction
- Buy Now with credit card: the buyer can purchase the digital item for a fixed price, using normal currency instead of cryptocurrency as bargaining chip
- All: all of the previous purchase modalities are available in the marketplace

Foundation year. The year of foundation of the NFT marketplace.

Website. Website of the NFT marketplace.

Description. Short description of the main characteristics of the NFT marketplace.

Country. Country where the headquarters of the NFT marketplace are based, or country of origin of the founder.

Continent. Continent to which the country of the NFT marketplace belong.

Type. Type of NFT marketplace, which could be one of the following:

- Marketplace: general NFT marketplace, open to everyone and many industries
- Gaming: platforms that sells NFT used for gaming purpose
- Art: marketplaces that sell exclusive digital art collections
- Collection: assortments of digital assets of the same style
- Exchange: the NFT marketplaces that belong to cryptocurrency exchanges
- Market aggregator. A platform that allows users to easily trade NFT collections from different NFT marketplaces without the need to visit those marketplaces. They combine inventories from multiple NFT marketplaces into one unified interface.

Other possible values:

- x: value is either 0 or not retrievable

3.2.3 Methods to collect additional information

In order to retrieve the information that were not available on Dappradar, many sources on the internet were used for this reason. Once the database has been extracted from Dappradar, each marketplace has been analyzed individually, both to manually check that it complied with the requirements described above to be included in the census, and to integrate information on additional variables. This phase of control and integration of the additional variables in the census has lasted from September 2022 until March 2023. The first reliable source was the official document provided by the specific marketplace, where there were reported information such as the governance of the marketplace, the commission fee, the royalty fee, purchase modalities and the proprietary token. If these values were not available in the document, it has been looked

for directly on the marketplace's website, and if still not found the information required has been asked directly to the client assistance of the marketplace available in the platform. If all of these options did not work to retrieve the information, the data was searched on the main social media channels of the platform, for example the Twitter, LinkedIn, Facebook account of the marketplace, or asked on the Discord official community chat.

Moreover, the information has been disclosed by other sources as well, independent from the marketplaces: specialized websites on blockchain and NFT news, such as coinmarket, or data analytics websites such as CryptoSlam, coinmarketcap, coinpaprika, nomics, coingecko, coinranking, but more general in news websites such as forbes.com.

Regarding the volume sales that took place in blockchains that were not Ethereum, Dune.com was utilized to retrieve the NFT volume market specifically. Other sources to compare these values were found in nftgo.io, coralcube.io, 0xtracker.com, cryptowisser.com and theblock.co, dapp.com.

The collaboration with the Blockchain and Distributed Ledger Observatory gave me the opportunity to participate in some events related to NFT and metaverse organized by the Digital Innovation Observatories of Politecnico di Milano, where I attended the pitch of different companies. Moreover, I had the chance to have short individual interviews with the Ninfa Labs NFT marketplace, whose founder collaborated with them.

More individual interviews with some marketplaces have been conducted, with the following companies:

- Ninfa Labs
- ItaliaNFT

At the end of the process, some marketplaces have been eliminated for insufficient information, or because they were projects that are not more in activity or could not be considered as marketplaces anymore. The result is a census of 100 marketplaces for which, whereas the data were available, all the variables in the database have been filled.

3.2.4 Conducting Interviews

Afterwards there are the description of the short interviews that have been conducted during the analysis, in order to enrich the report and retrieve the missing information that could not be retrieved in the literature.

- Ninfalab, 17/01/2023

Interview to Brando Bonaretti, CEO and founder of Ninfa Labs, an art gallery based in Milan which is managing a curated NFT marketplace that sells exclusive digital art pieces. Brando, after graduating in Politecnico di Milano in management engineering, has then worked for BCG and Amazon. He mixed his experience in retail with his passion in digital transformation: indeed in 2017 he invested in cryptocurrency and joined its community. He noticed that NFTs were a great opportunity to invest in, since the digital technology impacted the product directly. He formed a team, which included crypto and art passionate people, and ex colleagues, with which he founded Ninfa Labs. The team is now formed by seven people, including three developers, Cosimo De Medici, Carlo Borroni and Pietro Berrini.

Like the majority of the NFT marketplaces, they sustain their business with a commission fee that is applied to every transaction that have place on their marketplace. In particular, they apply 0% on primary fees, to lower talent entry barriers on the platform and give artists the chance to earn 100% on their sales via the buy-now option at 0%. The marketplace applies 0% on basic services, and between 5% and 15% on advanced services. In this way, it is the first marketplace that has introduced a freemium model. Right now, Ninfa Labs is placed on 6th place in the world in the art segmentation.[43]

Royalties are always recognized at 10%, to respect the social contract. Indeed, the owner does not support the latest trend for which some marketplaces has given the buyer the option to set the royalty as optional, by not rewarding in any way the artist of the digital piece.

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[43] According to Cryptoart.io

One of their main selling points is their friendly user interface. Indeed, he trusts her UX/UI developer and thinks that it is time for Web3 to fill the distance from traditional online retailers. They do it with smoother user experiences, facilitated browsing via enhanced filtering options and advanced product discoverability via randomized items displays and personalized suggestions. In his opinion, this is a difference that will be crucial for the future of the marketplaces.

All data and transactions are saved on-chain. Although Brando thinks that saving data off-chain gives many advantages like allowing users to skip the creation of the wallet and make the registration of the platform much smoother, he thinks that in this way one of the main advantages of the blockchain technology, the transparency, is lost.

The governance of Ninfa Labs is centralized. Ninfa is a curated marketplace, not based on a decentralized autonomous organization (DAO). Indeed, it is a closed platform in which not everyone is allowed to enter. There are two filters of selection: in one way, some selectors choose some members that are allowed to join the platform from the artists that have made an application. Otherwise, Ninfa Labs makes collaborations with brands and art galleries that manage creators. Once validated, these can invite their personal artists in the platform. At the moment, they are not considering becoming a DAO in the future, so they are not thinking about the introduction of a token either, which would ruin the evaluation of the society, that aims to become a curated multi category high-end retail for digital collectors. *"Moreover, he considers the token just a way to raise funds".*

The crypto crisis the world is living in the last months is not bothering Brando at all. He thinks that this drop of the market is just a phase of adoption of the technology, which lives very short and impulsive interests. Some technologies are speculated, but a careful analysis about the NFT marketplaces and cases indicates a clear growth. Some examples are the crypto crisis in 2018 and the dotcom bubble in 2000, when a lot of society failed, but Amazon succeeded thanks to a solid team. Brando thinks that this is a phase in which all the players that are opportunistic and lack a vision are going to be cut out.

Right now, Brando is still skeptical about the metaverse, but he thinks that it will develop in the future through the augmented reality and immersive visors. People will have to accept the existence of their digital identity other than their real one, and the firms will have to replicate to users the real needs. For example, in a world where all your friends are connected, it will be important to have a nice and comfortable house, but until then the phenomenon is still considered like a game. In his vision the NFT marketplace will be the shop of the future.

Regarding the regulations of crypto world, Brando thinks that Italy in particular is considering the theme with superficiality. He is aware that technologies like AI evolve in a much faster way than how regulations do and thinks that there is the lack of people who is able on one side to write down new regulations but on the other side understand the technology by a technical point of view. Indeed, in Italy there are some differentiated rules applied on retail and on crypto companies, but societies struggle to identify the category to which they belong. Ninfa Labs is compliant for all the categories such as billing and privacy, despite there is no clarity towards the users. Crypto is a technology that allows any country to be the leader, despite the location, and Italy could be in the top countries, but the regulations take too long to be approved. This is a wasted opportunity, since around 6 million people have invested in crypto in Italy, around the 10% of the whole population, so there would be potential clients.

- sudoswap, 6/12/22

This conversation was held via Discord chat with Owen, a team member of sudoswap. The main topic discussed were the future of the governance of the platform and the data saved. The user affirmed that the marketplace is introducing a governance driven by $SUDO token, which will be used for sudoswap and other related built. Then, he assured that all transactions are saved on-chain. Regarding the royalties, since sudoswap is a permissionless exchange, they are not enforced at the moment. Finally, regarding the future of NFTs in general, he thinks that the most important factors in the market will be the innovation of NFTs and the ease of use of user experience of the marketplaces.

- NFTItalia, 9/2/23

NFTItalia was born with the intent to bring the Made in Italy in the future of the Internet, the Web3. The firm, with headquarters in Milan, was founded in 2021 from two Italian entrepreneurs, Marco Capria and Achille Minerva. NFTItalia is a curated NFT marketplace that aims at exclusiveness. In the NFT field the auto-publishing is not conceded: only the true excellence with high intrinsic value become digital art pieces. The firm selects one by one the digital art pieces in order to promote the creations made from the famous Italian characters or are affiliated to the Made in Italy style.

The marketplace sustain itself with two revenue streams: the commission fee on the NFT sales and the furniture of Web3 technology services to other firms, but in the future are looking on the opportunity given by the Metaverse. They accept fiat payment through the platform Circle.

They work on-chain: Layer 1 (ERC-20) + Layer 2 (Polygon). The royalty fee put is set between 5% and 7%, and they are not considering setting it as optional for the buyer at the moment. In 2022 the platform has sold more than 2000 NFT, with more than 5000 active users in the last month. The marketplace is not a DAO and is not considering any projects regarding it at the moment.

The team of NFTItalia are not worried about the crisis that the world of NFT is living right now and are aware that every technologic innovation lives a great hype phase in the beginning and think that drop of the market serves to delete all the projects that are purely speculative and to orient the market to applications that are really useful. The applications are going to set the scenarios of this technology, and the term NFT will be always less popular but will be used more for various finality, such as certification of rare collections, copyright protection and metaverse assets.

They are very enthusiast regarding the regulation that whole the web3 is going under, since transparency is one of their main values and supports the chain-analysis for the blockchain transaction.

Other interviews were held with the teams via chat on the Discord platform of the following marketplaces, in order to retrieve some information not found online: X2Y2, NFTAir, Blur, Playdapp and Megapont.

3.2.5 Empirical analysis

The empirical analysis has been developed to provide an observation of how NFT marketplaces are currently operating in the international scenario. It describes how well the frameworks suggested by the Observatory and found in the literature review adhere to the actual world.

To find pertinent components for the innovation of these technologies, this analysis has been carried out. As a result, it has been carried out by segmenting the analyses into a number of subjects, with each topic examining the numerical presence of NFT marketplaces as well as the amount of funding they have received.

The topics of the analysis are the following:

- Overview
  - Yearly distribution
  - Geographical distribution
- Business analysis
  - Type of marketplaces
  - Commission fee
  - Royalty fee
  - Purchase methods
  - Credit card
  - NFT minting
- Technological analysis
  - Blockchain platforms
  - Governance
  - Proprietary token
  - Data savings storage
  - Standard

The analyses have followed a common scheme that provides:

1. Description of the results: description in details of the numbers and percentages of the results for each analysis conducted from the numerical point of view of the NFT marketplace.
2. Consideration of the results: the key findings that resulted from taking into account each analysis is outlined, and possible areas for more research are emphasized.

3.2.6 Consideration on outlier values

It is important to evidence a consideration that has been made on the analysis of the sample, in order to gather a better understanding of the current scenario.

The analysis of the marketplaces was made during October 2022, when many changes were happening, such as the merge of Ethereum and the introduction of the possibility to set the royalty fee as optional. For this reason, many things have changed after a short time and many marketplaces have gone bankrupt and many other have raised.

Moreover, the marketplaces offered by the major crypto exchanges such as Crypto.com and Binance offered to the public only data about some of the blockchains they supported or data about the exchange as a whole and not data pertaining exclusively to their NFT marketplace, so it was decided to gather them in another database from the other marketplaces.

Therefore, the statistical distributions about volume sales and number of traders regarding NFT marketplaces that are offered by exchanges are not included in the report of the following sections.

4. Empirical analysis

The empirical analysis has been presented in this chapter, together with a detailed explanation of the most important findings. The analysis has been divided in three main sections: the first part describes the global ecosystem of NFT marketplaces in the world. In the following section the analysis has focused on business aspects, in particular investigating the principal sectors in which NFT marketplaces operate and their business models; in the last section the investigation has addressed the technical aspect of the NFT platforms adopted by the marketplaces, with particular focus on the blockchains and the tokens.

4.1 Diffusion of innovation: NFT and marketplaces

4.1.1 An overview of NFT marketplaces

This census includes all marketplaces born from 2017 that sell NFTs and that during the period of analysis were between the best performing marketplaces that had a monthly volume of sales over $0 USD, an all-time volume of sales over $5000 USD, and more than 50 active wallets. A total of 100 NFT marketplaces have been analyzed, including the ones offered by the exchange platform for which not all data could be retrievable.

These marketplaces together raised a total volume of around $50 billion USD.

Total marketplaces	Volume sales	Average	Median
100 marketplaces	50 billion	624 million	10 million

Table 4: total, average and median of volume sales of NFT marketplaces

Volume sales	Marketplaces		Volume sales	
Over 1 billion	6	7%	$44.139.695.280	85%
Between 100 mln & 1 bln	17	20%	$6.989.493.742	14%
Between 10 mln & 100 mln	19	23%	641.774.451	1%
Between 1 mln & 10 mln	24	30%	85.006.428	<1%
Under 1 mln	17	20%	5.699.515	<1%

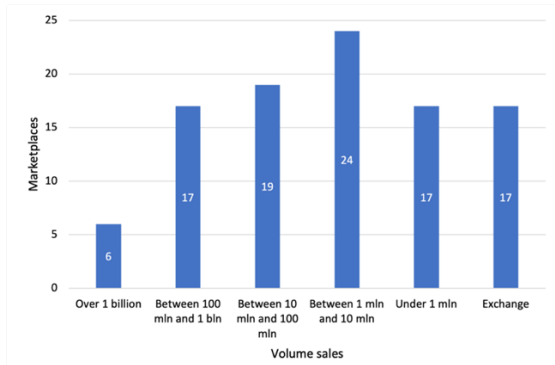*Table 5: distribution of NFT marketplaces by volume sales*

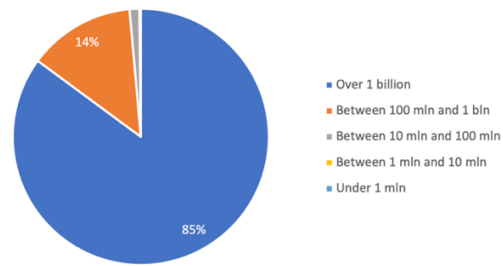*Figure 1: distribution of NFT marketplaces by volume sales*

Figure 2: distribution of volume sales by cluster

The 17% of the marketplaces have been excluded from the collection of data regarding volume sales, since they belong to a cryptocurrency exchange, and it was impossible to distinguish their sales coming from the NFT marketplaces from the ones coming from cryptocurrency platform.

From this first overview it has emerged that the market is dominated by small group of marketplaces, the ones that have the highest volume sale, over $1 billion USD. The most of the NFT marketplaces had a volume sale between $1 million and $10 million, that with its 24 cases takes the 30% of the database analyzed. This cluster is composed by marketplaces that are relatively new or did not become popular. Then, 19 NFT marketplaces have a higher success with the all-time volume sales that is ranged between $10 millions USD and $100 million USD.

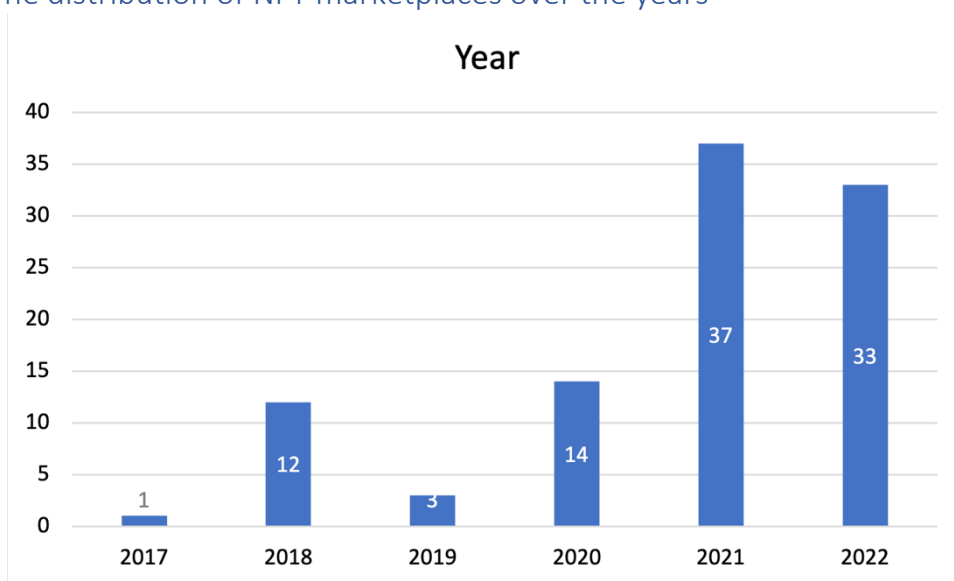## 4.1.2 The distribution of NFT marketplaces over the years

Figure 11: distribution of NFT marketplaces over years

The analysis has been conducted on the temporal distribution of the founding year of NFT marketplaces over the investigated period, from 2017 to 2022.

From the distribution of NFT marketplaces per year of foundation, it is possible to note that in the first three years there was not much interest in the NFT market, and the number of foundations remained quite low. The first NFT projects of the batch to be founded are CryptoPunks and CryptoCats (not included in the database), which were both launched in 2017. Then, in the following year, 12 marketplaces were founded, but in 2019 only 3 were launched.

During the last three years of analysis there has been a strong growth, with a peak in the two-year period of 2021-2022. Overall, from 2020 to 2022 there has been a sharp increase in births of NFT marketplaces. The number of founded marketplaces increased from 3 to 14 in 2020. The following year 2021, the number of marketplaces has more than doubled and reached the peak of 37 NFT marketplaces. A slightly lower value, but still very high, has been recorded in 2022 when 33 marketplaces were founded. However, the 2022 numbers are to be considered incomplete since, as explained in the methodology section, the census contains only the data of the first three quarters of that year.
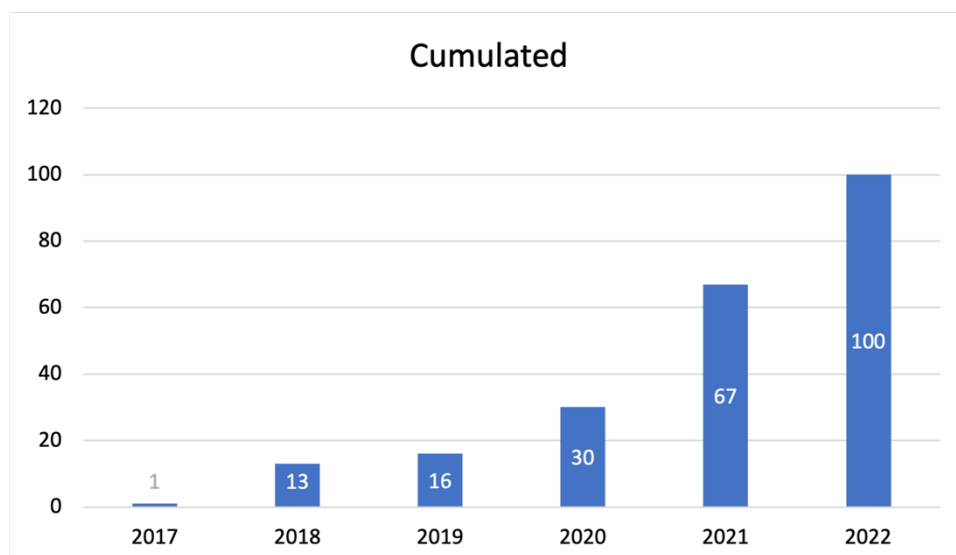

Figure 12: cumulated distribution of NFT marketplaces over the years

Then, the cumulative yearly amount of NFT marketplaces is outlined. Despite the decrease observed in 2022, the cumulative birth curve of NFT marketplaces has experiences intense increase, outlining a globally growing market.

4.1.3 The geographical distribution of NFT marketplaces

The geographical distribution of NFT marketplaces by continent has been examined in this paragraph in order to provide a global picture of marketplace presence and to give cues as to where this technology is evolving the fastest.
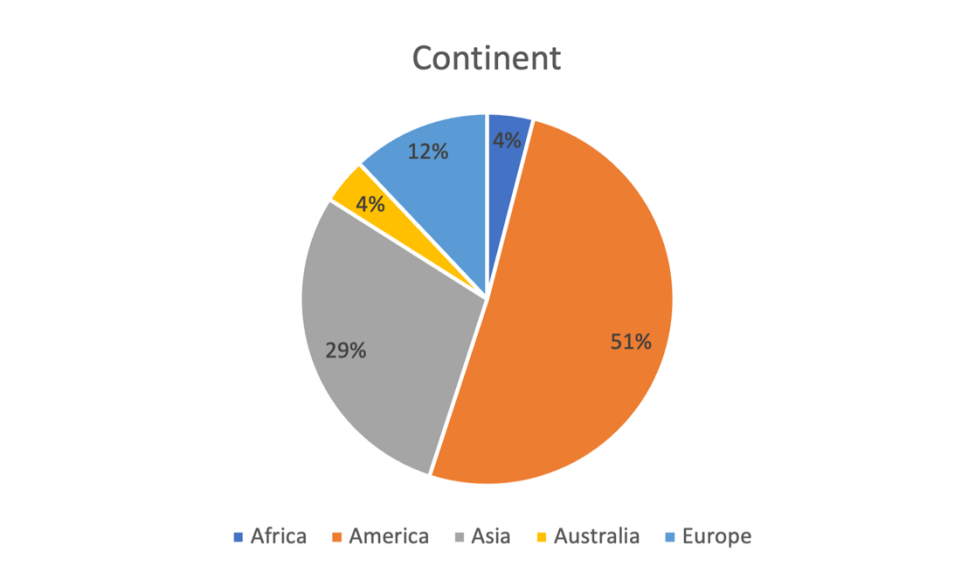
Figure 13: distribution of NFT marketplaces by continent

The results by geographical analysis are shown in the figure above. From a numerical point of view, America is by far the most active, with 51% of NFT marketplaces located there. Then there is Asia and Europe, which hosts respectively 29% and 12% of the NFT marketplaces. The remaining 8% is equally divided between the areas less populated by NFT marketplaces, Africa and Australia, with 4% of the marketplaces each.

Continent	Volume sales [$]	Percentage	Marketplaces
Africa	8.170.230	0,02%	4
America	41.437.294.910	79,90%	51
Asia	9.185.641.676	17,71%	29
Australia	979.670.000	1,89%	4
Europe	250.892.600	0,48%	12

Table 6: distribution of all-time volume sales by continent

Figure 14: distribution of all-time volume sales by continent

The table above shows the distribution of the volume sales of all time[44] of NFT marketplaces distributed by continent.

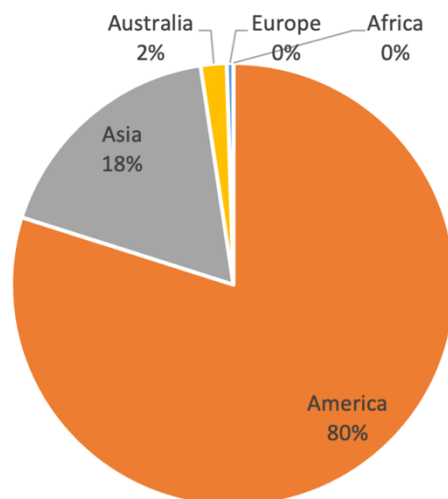The American continent's NFT marketplaces dominate the volume sales of the report. The 79,9% of the volume sales take place in NFT marketplaces that are located in America, where 51% of the marketplaces analyzed are located. Then, far away there are the Asian NFT marketplace, which take 17,71% of the all-time volume sales of NFT marketplaces. The rest is subdivided in small percentages by the NFT marketplaces of other continents Australia, Europe and Africa.

America

Country	Marketplaces	Percentage
United States	40	79%
Brazil	3	5%
Cayman Islands	3	5%
British Virgin Islands	3	5%
Canada	2	4%
Bahamas	1	2%

Table 7: distribution of NFT marketplaces by nation in America

The table shows the nations of the American continent where the largest number of NFT marketplaces are located.

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[44] According to DappRadar

As expected, the country where most NFT marketplaces are born is the United States, with 40 marketplaces located, representing 79% of the marketplaces analyzed in America. The United States has always been a good environment for the birth and evolution of digital and technological projects. For this reason, it is not surprising that it is in first place in the ranking of NFT marketplaces. Most of the marketplaces are based in New York, a city that offer a lot of opportunities in term of job and economy. The biggest marketplaces that it hosts are OpenSea, Blur and Magic Eden.

Far below United States, are positioned the British Virgin Islands, countries that are considered particularly suitable for innovative venture due to its political and social stability and favorable taxation. The same speech can be made about the British Virgin Islands, that haven't imposed any specific taxes against cryptocurrencies. Here are based Mochi marketplace and the exchange BitFinex.

Brazil is considered the second country in the global rankings for NFT adoption, behind Thailand, since it is estimated that in August 2022 there were 5 million users of blockchain-based digital collectibles in the country.[45] Indeed, some local phenomena contribute to strong adoption of NFTs in Latin American nations. Among them there is the growth in the number of users of play-to-earn (P2E) games. Another reason is the relationship that has been developed between the sport world and non-fungible tokens: several football clubs, for example, have launched collections of NFTs to increase fan engagement and create a new revenue stream. In addition, the purchase of NFT by famous Brazilians, such as footballer of Neymar Jr, helped to spread the concept to general public.

Canada is the country where two important NFT projects born, CryptoPunks made by the Larva Labs studio, that had a huge contribute to the NFT craze of 2021, and NBA Top Shot platform, made by Dapper Labs, that allows fans to buy, sell and trade NFTs of NBA video highlights.

Country	Volume sales [$]	Percentage
Brazil	58.556.910	0,14%
British Virgin Islands	3.420.000	0,01%

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[45] According to German consultancy Statista

Canada	3.911.350.000	9,44%
Cayman Islands	989.610	0,00%
United States	37.462.978.390	90,41%

Table 8: distribution of volume sales by country of America

The United States' marketplaces take more than the 90% of the volume sales of the Continent. Then, 9% of the volume sales analyzed happen in Canadian continent, with the collections CryptoPunks and NBA Top Shot, while the rest take place in the other countries Brazil, the British Virgin Islands and Cayman Islands, which take a small percentage.

Asia

Country	Marketplaces	Percentage
Singapore	10	36%
China	4	15%
Israel	3	10%
Japan	3	10%
Taiwan	2	8%
Indonesia	1	3%
Korea	1	3%
Lebanon	1	3%
Dubai	1	3%
New Zealand	1	3%
Hong Kong	1	3%
Vietnam	1	3%

Table 9: distribution of NFT marketplaces by nation in Asia

The table shows the distribution of NFT marketplaces in the Asian continent.

The country with the highest number of presences is Singapore, with 10 registered marketplaces that represents the 36% of the NFT marketplaces analyzed in Asia. Its biggest platforms are LooksRare, Gem and Enjin marketplace. Indeed, the country seemed to become a global center for blockchain technology, thanks to its favorable business environment. However, the collapse of the popular token Terra Luna and the crypto exchange FTX because of a crippling liquidity crunch have been particularly shocking for the country, which invested $275 million USD in its state fund Temasek.

Immediately following is China, which hosts 15% of NFT marketplaces analyzed in Asia. China was initially cautious in the development of NFT and blockchain technology, but then built a platform that aims to facilitate the deployment of blockchain technologies called Blockchain-based Service Network (BSN), linked to the Chinese government. The country has imposed restrictions on the resale of NFTs, but is expected to ease them in the future, with the launch of its first national NFT marketplace in 2023. Its biggest platforms are the DApp Decentraland and the exchange Binance, which hosts its NFT marketplace Binance NFT. NFT purchases take place directly through RMB, using traditional non-crypto means, such as Alipay, WeChat Pay and bank cards for payment processing.

In the continent in general, NFT became very popular in the gaming sector, since a lot of Asian players join the play-to-earn blockchain games, which reward players with cryptocurrencies and often integrate NFTs into their gameplay. Indeed, for countries with high web traffic to NFT marketplaces, especially Thailand, Vietnam and the Philippines, a large portion of that NFT-related traffic may therefore come from players of blockchain games. Blockchain games like the Vietnamese Axie Infinity, have been particularly popular in the Philippines, though these games have seen a considerable drop in users in recent months as crypto prices have collapsed. Moreover, the emergence of NFTs has created a space for digital artists in India and Indonesia.

Country	Volume sales	Percentage
China	990.450.000	10,78%
Dubai	26.260.000	0,29%
Hong Kong	69.344.000	0,75%
Indonesia	20.120.000	0,22%
Israel	113.301.880	1,23%
Japan	681.710.000	7,42%
Korea	3.170.000	0,03%
Lebanon	2.460.000	0,03%
Singapore	2.578.157.816	28,07%
Taiwan	450.660.000	4,91%
Vietnam	4.250.000.000	46,27%

Table 10: distribution of volume sales by country in Asia

The country where the NFT marketplaces made the highest volume of sales is Vietnam, where the platform Axie Marketplace alone has taken 46,27% of the sales. The second country is Singapore, with 28,07% of the volume sales of the marketplaces analyzed made by its 10 marketplaces. The third country is China, of which marketplaces have raised the 10,78% of the volume sales. After Japan, the rest of the Asian volume sales is divided in small percentages between the other countries.

Europe

Country	Marketplaces	Percentage
Switzerland	2	18%
Germany	2	18%
Belgium	1	9%
United Kingdom	1	9%
Serbia	1	9%
Netherlands	1	9%
France	1	9%
Russia	1	9%
Scotland	1	9%

Table 11: distribution of NFT marketplaces by nation in Europe

Table 3 shows the distribution of NFT marketplaces by nation in Europe.

The two leading countries in Europe for number of marketplaces are Switzerland and Germany, which both have 2 marketplaces, representing the 18% of the analyzed marketplaces in Europe each.

Switzerland is one of the most advanced financial centers in the blockchain sector. To testify this, the Swiss finance ministry made an initiative to welcome host blockchain companies, such as the Japanese investment bank Nomura, which decided to locate its new cryptocurrency business in Switzerland. Its biggest NFT marketplace is Solana Monkey Business, a collection of 5000 unique 24x24 pixels randomly generated monkeys.

In 2019, Germany was the first country to adapt a blockchain strategy to harness the technology's potential for advancing digital transformation and help make it an attractive hub for the development of applications such as NFT. Now we see 5.8% of

German adults currently hold cryptocurrency, or approximately 4.9 million people in 2022. [46] Its biggest platform is KnownOrigin, a digital art marketplace powered by Ethereum.

The rest of the marketplaces analyzed are equally distributed in other countries of Europe. Important projects to mention are Objekt.com NFT marketplace and the Russian game Waves Ducks. In Europe, the NFT market witnessed significant growth recently. The NFTs have become prominent across countries such as the United Kingdom, France and Italy. Every industry finds an innovative NFT use case, from sports to real estate to entertainment.

Country	Volume sales	Percentage
Belgium	110.760	0,04%
France	12.270.000	4,89%
Germany	8.089.830	3,22%
Netherlands	1.430.000	0,57%
Russia	33.890.000	13,51%
Scotland	79.220	0,03%
Serbia	32.540.000	12,97%
Switzerland	159.080.000	63,41%
United Kingdom	292.790	0,12%

Table 12: distribution of volume sales by country in Europe

The NFT marketplaces in Switzerland have taken the majority of the NFT sales with its 63,41% of the volume sales, thanks to its collection Solana Monkey Business and exclusive art platform Objkt.com. Then, far from it the Russian gaming collection Waves Ducks have brought the 13,51% of the volume sales and the Serbian platform SolSea has led to 12,97% of the all-time volume sales. After France, which took the 4,89% of the volume sales with its art marketplace Fxhash, and Germany, which took 3,22% with its marketplaces KnownOrigin and Mintbase, the remaining sales are divided in small percentages below 1%.

Africa

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[46] According to Cointelegraph

Country	Marketplaces	Percentage
Seychelles	3	75%
Nigeria	1	25%

Table 13: distribution of NFT marketplace by nation in Africa

The table shows the distribution of NFT marketplaces by nation in Africa.

The country with the biggest number of NFT marketplaces in Africa are the Seychelles, with 3 marketplaces representing the 75% of the marketplaces analyzed in Africa. These, are all represented by the marketplaces of exchange platforms, including OKX, Kucoin and AAX. Seychelles has taken the frontier of crypto, not because of its trading volume but due to its government participation. A nationwide survey showed an estimated 1257 crypto owners exist among 107,118 people. This is relatively low compared to other nations, such as Nigeria, with more than 30 million crypto owners.

Nigeria hosts Hashgreed, the first and biggest NFT marketplace of Africa. In this country, a new bill in the works could let local regulators recognize cryptocurrencies as capital per investment.

Since the marketplaces of the Seychelles belong to exchange platforms for which the volume sales exclusive to the NFT could not be retrieved, all the volume sales of $8.170.230 USD collected in Africa come from the Nigerian marketplace Hashgreed.

Australia

Australia has 4 NFT marketplaces located in its territory, between the ones that have been analyzed in the report. These include the recently developed Immutable X marketplace, which works in the gaming industry, based on the new homonymous blockchain platform, which simplifies the creation of non-fungible token projects for developers. Other important projects to mentions are Atomic Market, a shared liquidity NFT market smart contract which is used by multiple websites to provide the users the best possible experience, and SuperRare, an exclusive digital crypto art marketplace

powered by Ethereum. Since more than one in ten Australian hold some form of digital currency, the non-fungible tokens are seeing a growth in the country. [47]

All the Australian marketplaces together raised an all-time volume of sales of around $989.670.000 USD.

4.2 Business applications: Industries and design solutions

In this section I take a closer look to the industries and the design choices that NFT marketplaces have took. A cross analysis between type of marketplace and blockchain supported will lead us to find the main business solutions and how they bring value. Eventually a brief analysis of the type of customer the solution addresses is outlined.

4.2.1 Type of marketplaces

In this section the focus is directed to the sectors to which the NFT marketplaces analyzed belong. In order to have a complete overview of possible infights, an analysis has been conducted on the distribution of NFT marketplaces by sector.

The classification has been made by taking inspiration from the classification taken from an article[48] has identified three types of NFT marketplaces: the "open" marketplaces, where anyone can mint and sell any type of NFTs, the "curated" marketplaces, where the platform determines which NFTs are allowed to be posted on its marketplace, and the proprietary marketplaces, that only offer NFTs created be the platform operator and do not facilitate the sale or display of other NFTs. During the analysis of various marketplaces, six types of NFT marketplaces have been identified, which are described subsequently. In order to understand to which category a marketplace belong, the descriptions provided by Dappradar were exploited, with the website of the platforms itself.

In order to make this cluster, these categories have been chosen:

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[47] According to the Q1 2022 Global Survey
[48] James G. Gatto (2023) – "NFT License Breakdown: Exploring Different Marketplaces and Associated License Issues"

- Marketplace: a general digital platform used for buying and selling any type of NFTs. These platforms allow people to store and display their NFT plus sell them to other in exchange of cryptocurrency or money. The market is open, as anyone can sell (and sometimes mint) their digital piece in the platform.

- Gaming: a platform selling NFT that can be used in game titles that operates in the blockchain. Throughout gameplay, players can earn real-world rewards, such as NFT that enable players to own the in-game assets that they earn or buy, such as weapon or avatar, which can be tradable NFTs as well. Some of the most popular NFT games to date include Axie Infinity, Decentraland and the Sandbox.

- Art: a platform that sell exclusively NFTs that are related to digital art collections. These platforms aim for a niche interested in art and sell exclusive digital pieces, like an art gallery. In order to sell as an artist your NFT in these curated platforms, you must send an application and be chosen by some selectors or belong to a brand or art gallery that made a collaboration with the platform. They team up with artists and brands to create collection of limited editions, high quality NFTs, exclusively available in their platform. The most popular are Super Rare, Foundation and Solanart.

- Aggregator: a network model which organizes the related unorganized service providers in one huge platform under one brand name. It is a platform that allows users to easily trade NFT collections from different NFT marketplaces without having to visit them. So, they combine inventories from multiple NFT marketplaces into one unified interface. The most popular are Gem and AtomicMarket.

- Collection: an assortment of digital assets released by an artist (or group of artists) containing a limited number of individual NFTs. Typically, most NFT collections consist of numerous NFTs that all conform to the same artistic style, with slight variation across each individual token. Some examples are CryptoPunks and Bored Ape Yacht Club.

- Exchange: NFT marketplace offered by a cryptocurrency exchange, which allows customers to trade cryptocurrencies for other assets, such as fiat money or other digital currencies. These platforms usually expand their interest, by selling not

only cryptocurrencies but NFTs as well, in other platforms affiliated by the main ones. The most popular are Crypto.com and Binance.

The classification may appear ambiguous because a category does not necessarily exclude another one and marketplaces could belong to more than one category. To solve these cases, it was decided to choose only the most suitable category for each marketplace, and the general open marketplace was the preferred type in case of ambiguity, since it is the most general case that can cover most platforms. A specific case is Blur, which is both a marketplace and aggregator, for which I decided to classify as a marketplace since it has become its main activity.
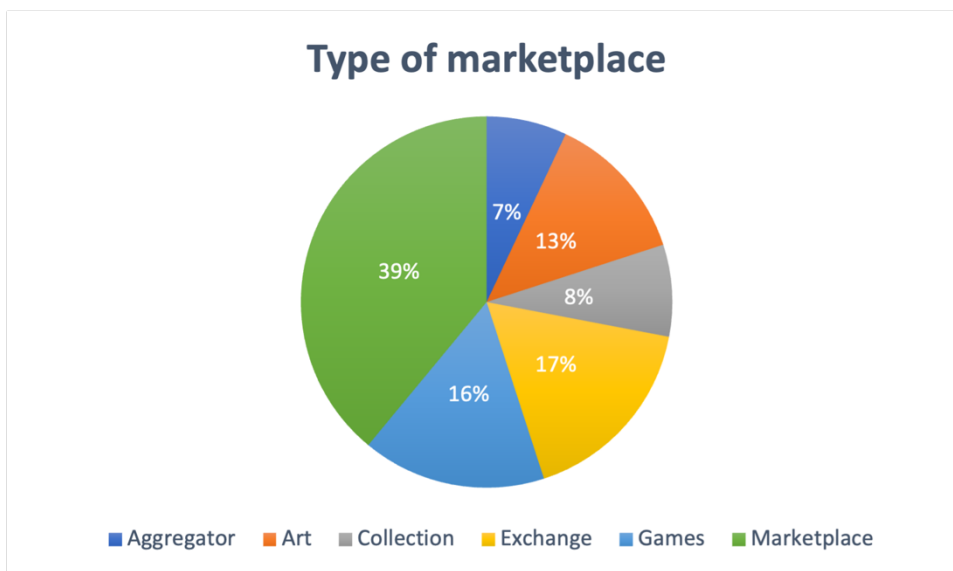

Figure 15: distribution of NFT marketplace by category

The figure shows the distribution of the NFT marketplaces by category. The type of marketplace that is most popular is the general one. Since it does not aim just for a niche, they can aim for the largest market becausethey can offer any type of NFT: art, gaming, membership, music, photography etc.

Then, the rest of market is more or less equally distributed between the other categories. The second most popular category is formed by the marketplace that belong to a cryptocurrency exchange. These have a lot of capital to invest in NFT, and these are an important part for their cryptocurrency ecosystem.

Gaming is one of the most important industries since it can exploit well the characteristics of the NFTs and englobe them in its ecosystems. The adoption of NFT token standards allows developers to preserve the rarity and uniqueness of some of these in-game items. With this system in place, players can claim ownership of game assets by purchasing, creating, or unlocking digital items.

Exclusive art marketplaces are the fourth most popular category, and the news about the most expensive digital art pieces sold during these years can testify that. NFTs are a good solution for this industry, since they can prove the ownership of the collector and give royalties to the original artist at the same time.

Collections were the first type of NFT to be launched and were initially sold in their proprietary platform but then have spread all over popular marketplaces.

Finally, aggregators are a new trend that are spreading only recently, but will lead to many benefits to the users, such as improved search efficiency, bulk purchases and one unified interface for all the NFTs.

Type of marketplace	Volume sales [$]	Percentage
Aggregator	1.427.421.336	2,75%
Art	1.610.028.229	3,10%
Collection	4.025.628.530	7,76%
Games	4.966.722.830	9,58%
Marketplace	39.831.868.491	76,80%

Table 14: distribution of all-time volume sales of NFT marketplaces by type of marketplace

The type of marketplace that has raised the highest volume of sales is the general marketplace, which covers the 76,8% of the volume of sales analyzed in the report. This category has even the highest number of marketplaces analyzed. This comprehends marketplaces that offer any type of NFTs, satisfying the requests of many markets, even the one of niche.

The second highest volume of sales of type of marketplace is the gaming one, that with its 7 marketplaces out of 100 have seen the 9,58% of the volume of sales analyzed. The NFT collections made 7,76% of the volume sales, while art marketplaces and aggregators have made respectively only 3,10% and 2,75% of the volume sales.

NFT marketplaces that belong to cryptocurrency exchanges have been excluded from this distribution, since it has not been possible to distinguish the volume sales that regarded exclusively NFT from the rest of the platform.

4.2.2 Commission fee

In this chapter there will be a comparison between the commission fees imposed by the marketplace for every transaction that customers have to pay for the service offered. Owners can charge a commission at a fixed or variable percentage, or fixed flat fees.

This is the main revenue of the marketplace. Thus, commission-based marketplaces have become one of the most popular and lucrative marketplace business models. The primary advantage is that merchants and buyers do not have to pay before getting some value from using the marketplace. All parties can operate on the marketplace for free. Moreover, sellers can focus on carrying out their business operations and increasing sales since marketplace handle payments.

These fees are charged in addition to the gas fees that are incurred for verification of every transaction that takes place on the blockchain, for example Ethereum.

However, 17 out of the 100 marketplaces analyzed have been escluded by this distribution for many reasons, such as the lack of information retrieved or a value that was not comparable to the one of the other marketplaces. Therefore, this analysis regard 83 NFT marketplaces.

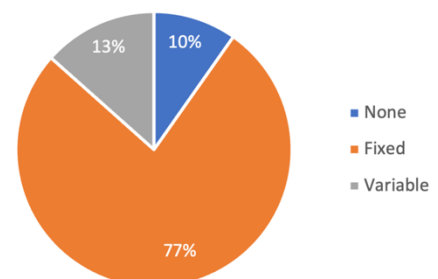| Commission fee	Marketplaces	Percentage
No commission	8	10%
Fixed	64	77%
Variable	11	13%

Table 15: distribution of marketplaces' commission fee by type

The figure and the table above shows the distribution of the marketplace's commission fee by the type of the commission, whether fixed or variable.

The majority of the NFT marketplaces charge commission fees that are fixed, meaning that they impose the same percentage or fixed flat fee for every transaction happening on the platform.

Indeed, just a small minority of NFT marketplaces charge variable commission fee, depending on many factors such as the size of transaction or the number of transactions that happened for a single digital piece, or the number of transactions that a user have done. For example, a marketplace may not charge any commission fee for the first transactions made by a user, but then may raise higher fees for the following transactions.

Finally, a few marketplaces do not charge any commission fee for the transactions but find their revenues in other ways such as advertisement or collaboration.

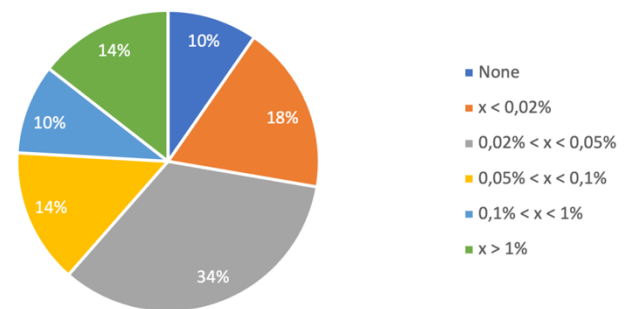| Commission fee	Marketplaces	Percentage
None	8	10%
x < 0,02%	15	18%
0,02% < x < 0,05%	28	34%
0,05% < x < 0,1%	12	14%
0,1% < x < 1%	8	10%
x > 1%	12	14%

Table 16: Marketplaces' commission fee distribution by percentage

The figure and the table above show the marketplaces' commission fee distribution by percentage of the transaction that is charged to the seller of the NFT.

The majority of the NFT marketplaces charge to the customers a commission fee that is between 0,05% and 0,10%. In particular, 10% of the NFT marketplaces charge 0,05% of commission fee.

Then, the rest of the commission fees imposed by the NFT marketplaces is more or less equally distributed between other percentages. The highest commission fee imposed by an NFT marketplace is 2,5%, the one imposed by OpenSea, which 5 other marketplaces have taken inspiration from. Some marketplaces set variable commission fee. For example, SuperRare takes 15% on primary sales and then 3% on secondary sales.

71 out of the marketplaces charge a commission fee that is lower than 1% of the transaction, representing the 86% of the NFT marketplace analyzed. The most popular value is 0,02%, implemented in 14 marketplaces that represent the 17% of the marketplaces analyzed. The second most popular value is 0,05%, implemented in 10 marketplaces that represent the 12% of the marketplaces analyzed.

3 NFT marketplaces that belong to cryptocurrencies exchanges charge a fixed flat fee, such as $0,40 and 0,010 BNB. All the other marketplaces charge a percentage of the transactions or none.

4.2.3 Royalty fee

In this section, there is the analysis of the royalty fee implemented by the NFT marketplaces. The royalty fee is the crypto payment given to the original NFT creator each time digital assets are sold on a marketplace. Typically, this is a percentage of the sale price that may typically range from 2,5% to 10% but it can vary based on the percentage set by the marketplace, the creator of the NFT or the buyer.

The original creator of digital collectibles usually sets royalties in NFTs at the time of minting, and then those royalties are coded into the smart contract's platform. This allow creators to get paid in perpetuity, as they keep earn more money for every new transaction being made on their digital work of art, keeping the copyrights under their name at the same time.

However, for 24 out of the 100 marketplaces analyzed the value of the royalty fee was not included for different reasons: it was not offered, as in a gaming marketplace the NFT offered are not created by artists but by the developers, or the value was not retrievable.

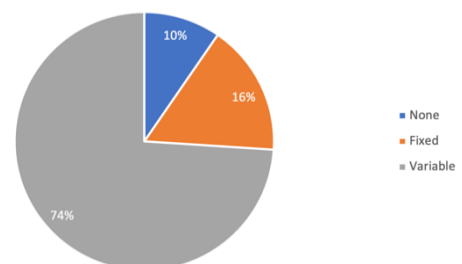| Royalty fee	Marketplaces	Percentage
None	7	10%
Fixed	12	16%
Variable	54	74%

Table 17: distribution of the royalty fee charged by the NFT marketplaces by type

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The figure and the table above show the distribution of the royalty fee charged by the NFT marketplaces by type. The majority of the marketplaces allow the creator to set the royalty fee right after the process minting of the NFT, giving them some maximum threshold that usually reach 10%, but in some cases can be set up to 40% of the transaction.

54 out of 76 marketplaces had a variable royalty fee, representing the 74% of the marketplaces analyzed. This variable can depend by many factors.

Royalty Fee	Marketplaces
0	6
0,01%	2
0,05%	3
0,10%	8
0,50% min	3
0.50%	2
Optional (buyer)	3
Up to 10%	9
Up to 11.11%	1
Up to 40%	1
Variable	38

Table 18: distribution of royalty fee of NFT marketplace by percentage

12 marketplaces have a more traditional fixed royalty fee, representing the 10% of the marketplaces analyzed. This is always a percentage of the transaction fee that is usually set around 0,5%, like the one set by Blur, or a value lower than that, such as 1%.

In 8 marketplaces creator royalties are not honored on the platform. This happen for various reasons: it can be choice of the design of the marketplace, or in other cases the NFTs that are sold on the platform are created by the creators of the platform, so there are no other creators to reward.

4.2.5 Purchase methods

NFT marketplaces are platforms where customers can whether sell or buy NFTs by using different methods. Usually users, in order to buy NFTs, have to purchase cryptocurrencies and charge them into a crypto wallet, connect this to an NFT marketplace and browse for NFTs to buy. There are many ways to buy an NFT. The

simplest one that marketplaces offer is by clicking a "Buy Now" button connected to a specific NFT, for a fixed price shown. Otherwise, the NFT can be sold in an Auction with a time limit. Or else, potential buyers can place a bid, which can be later rejected or accepted by the seller.

Purchase method	Marketplaces
Fixed	98%
Auction	53%
Bid	67%

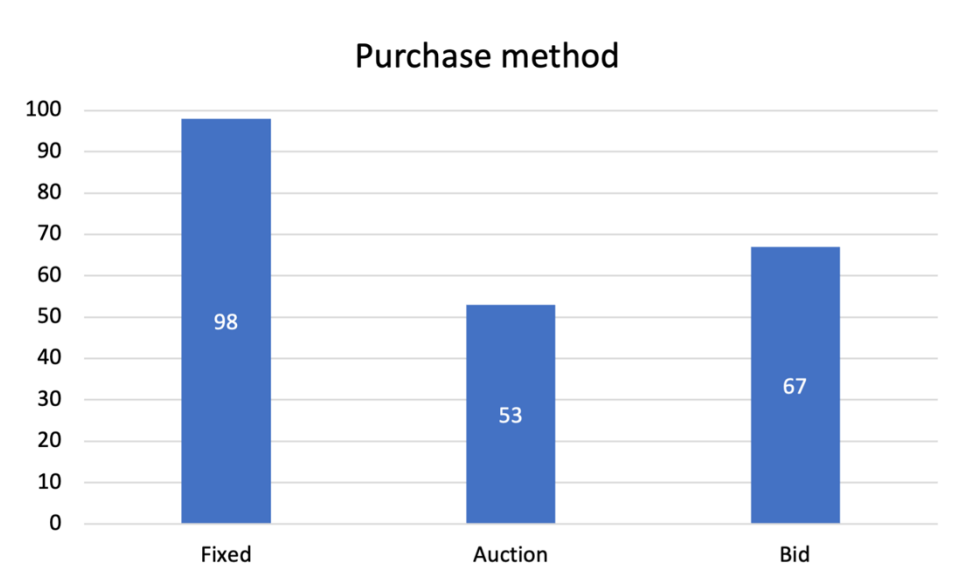*Table 19: distribution of purchase method of NFT marketplaces by type*

Figure 16: distribution of purchase method of NFT marketplaces

The figure and table above show the distribution of the purchase methods offered by NFT marketplaces, in terms of percentage of acquisition by the platforms.

98 marketplaces out of 100 allow users to buy NFT at a fixed price, with the "Buy Now" option. This is the simplest way, since the NFT can be purchased any time during the sale period and without any additional involvement from the seller. A marketplace may allow this option only for certain collections.

53 marketplaces out of 100 put NFT up for an auction, where potential buyers can bid on the item. The NFT will either go to the highest bidder, or the seller can choose to accept any offer during the auction.

67 marketplaces out of 100 allow to place bids. Potential buyers can make an offer on any item, even if not listed on sale. Otherwise, they can also make an offer for a listed item, in order to offer less than its listed sale price.

Purchase method	Marketplace
All	48
Auction/Fixed	3
Bid	1
Fixed	29
Fixed/Auction	1
Fixed/Bid	17
Auction/Bid	1

Table 20: purchase method distribution by offer

Almost half of the marketplace, 48 to be precise, offer all three purchase methods. This allows users to choose between the three options and have a large freedom of choice, both for sellers and buyers.

29 marketplaces out of 100 allow customers to buy NFT exclusively with the "Buy now" option for a fixed price. This happens mostly in marketplaces that deals with niche markets, such as gaming, to let the players set a goal to buy the assets desired.

Then, the rest of the marketplace allow only two purchase methods out of three, and 17 of them does not set up any auction.

A few marketplaces, 4 to be precise, offer a fourth purchase method. Customers can purchase a "mistery box", which contain some randomized NFT that can represent a higher or lower value than the price that the user paid for it. This is used mainly in NFT marketplaces that deal with gaming but has not been considered as one of the main purchase methods in this report.

4.2.6 Credit card

Credit card	Marketplaces
Yes	74
No	26

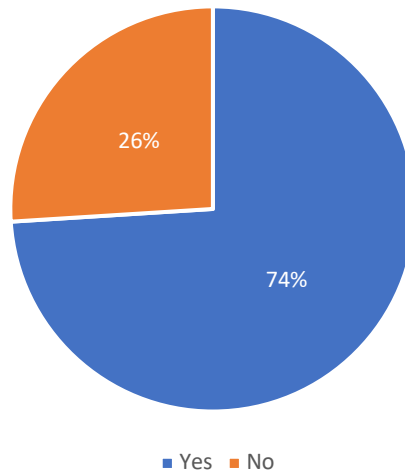*Table 21: distribution of credit card option in marketplaces*

Figure 17: distribution of credit card option in marketplaces

74 out of 100 NFT marketplaces allow to purchase NFT not only through a crypto wallet by using cryptocurrencies, but also directly with credit cards. This has been possible with the collaboration of third parties like MoonPay, a platform that enables the customers to buy NFT directly with credit card, simplifying in a considerable way the purchase of NFTs. Other platforms that allow this are Stripe, Switchere, Wert, Winter, Carbon Money and Wire.

4.2.7 NFT minting

Some NFT marketplaces allow to easily mint NFT directly on their platforms.

Mint NFT	Marketplaces
No	29
Yes	63
Limited	8

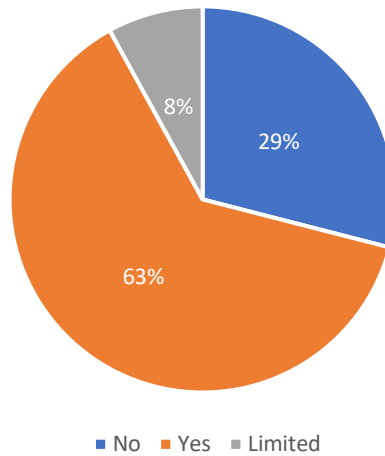*Table 22: distribution of possibility to mint NFT on marketplaces*

Figure 18: distribution of possibility to mint NFT on marketplaces

63 out of 100 marketplaces allow their users to mint NFT directly on their platform. In some cases, the user can simply upload their digital file, such as JPEG, MP3, GIF or PNG compatible with the preferred marketplace, and after the payment of a variable gas fee can put it up for sale on the platform.

29 marketplaces do not give this opportunity to their customers. This may happen because the platform only sell exclusive collections that are made by the developers of the marketplaces or collaborations with specific brands or artists.

8 marketplaces allow users to create only certain type of NFTs, with the parameters and restrictions set by the platform. This happens when the NFT sold are digital pieces used by blockchain games, so people are not able to create personalized contents, but only to set some parameters of the digital item wanted.

4.3 A focus on technological aspects

In this section of the analysis, I am going to address the technical aspects of NFT marketplaces. Indeed, the analysis of the literature show that there is a lack scientific papers concerning NFT marketplaces that concerns this aspect. So, it is considered important to cover the technological choices that NFT marketplaces have made in their design, comparing the technical configurations adopted with the volume sales produced.

In particular, three aspects have been investigated: the blockchain platforms supported by NFT marketplaces, the presence of a proprietary token and how they have been used in the governance, and the storage in which data about transactions are saved, whether on-chain or off-chain.

4.3.1 Blockchain platforms

Every NFT marketplaces support different blockchains to work on and in this section the distribution of the various network is highlighted.

Blockchain	Marketplaces	Volume of sales	Percentage
Many blockchains	21	45.026.294.615	72,71
Ethereum	24	4.949.901.478	7,9933
BNB Chain	8	112.017.780	0,1809
Solana	7	3.829.690.681	6,1843
WAX	6	3.084.970	0,005
Tezos	6	739.434.155	1,1941
Others	27	7.265.356.356	11,732

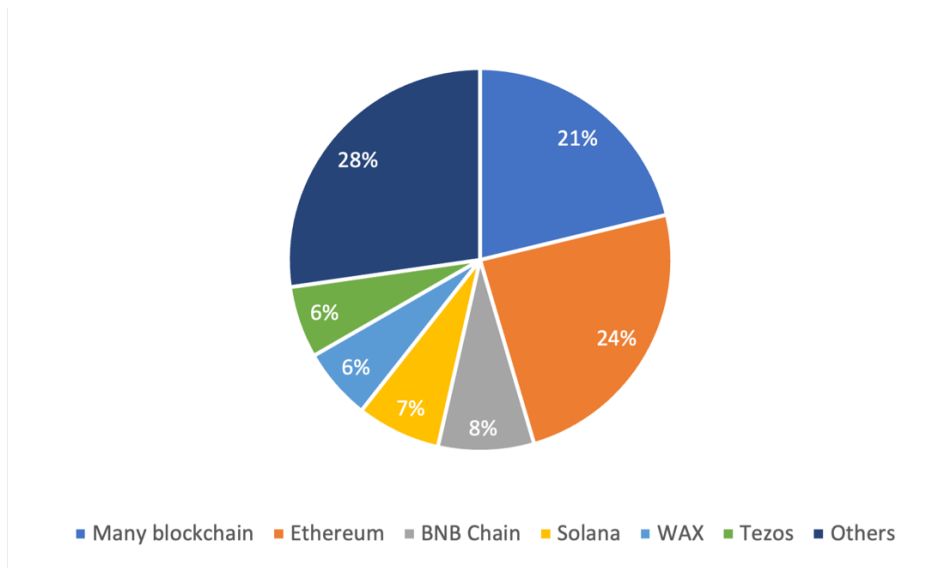*Table 23: distribution of marketplaces and volume sales by blockchain*

Figure 19: distribution of NFT marketplace by blockchain supported

From the figure 12 a first important observation emerges: many NFT marketplaces, the 21% percent to be precise, do not support a single blockchain network, but they interface with various blockchains to provide their service. This is the case of models of open marketplaces like OpenSea, or marketplaces that belong to cryptocurrencies exchanges.

In the domain of NFT marketplaces that use a single blockchain, Ethereum prevails clearly, being used by 24% of NFT marketplaces included in the report followed by BNB Chain and Solana.
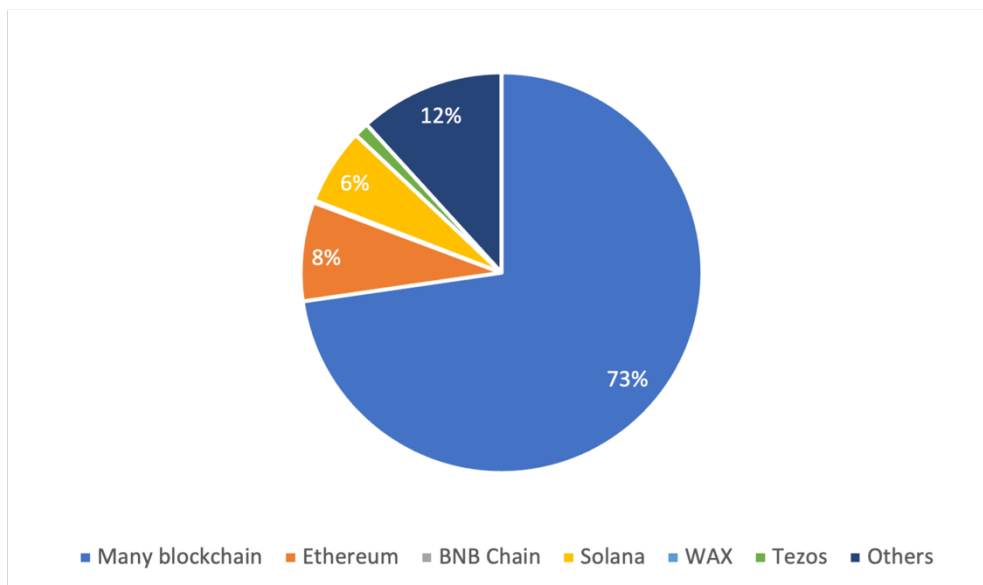

Figure 20: distribution of volume sales by blockchain

The figure above shows that most of the volume sales, the 73% to be precise, happen in marketplaces that support multiple blockchains. Then, the exclusive blockchain where most of the volume sales take place exclusively is Ethereum, followed by Solana.

Blockchain	Marketplaces
Ethereum	38
BNB	18
Polygon	18
Solana	12
WAX	7
Tezos	6
Avalanche	4
Optimism	3
Moonbeam	3
Zilliqa	3
Celo	3
Immutable X	3
Arbitrum	3
Klaytn	3
Flow	3
Moonriver	2
Hedera	2
Stacks	2
BKEX	1
Fantom	1
Crypto.org	1
Heco	1
Tron	1
Ronin	1
Aurora	1
Hedera	1
Lightning	1
Loopring	1
Near	1
Oasys	1
Theta	1
Waves	1
EOSIO	1
Aptos	1

Table 24: distribution of blockchain network in NFT marketplaces

The table 19 shows the number of marketplaces that adopt each blockchain network, whether exclusively or with other networks.

Ethereum is the network that is supported by the greatest number of NFT marketplaces, to be precise the 38% of the marketplaces analyzed. Then, the most popular blockchains are BNB Chain and Polygon, both of which are supported by the 18% of the NFT marketplaces of the report. Solana is supported by the 12% of the marketplaces. After that there are WAX, Tezos and Avalanche, which are supported respectively by the 7%, 6% and 4% of the marketplaces.

Ethereum

Ethereum is the world's largest blockchain ecosystem after Bitcoin and one of the first to be created and after "The merge" and the transition from proof-of-Work to proof-of-Stake has gained many advantages. For this reason, it is supported by so many marketplaces of the report.

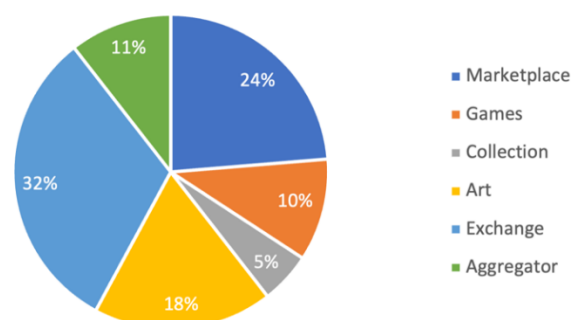| Type	Marketplaces	Percentage
Marketplace	9	24%
Games	4	10%
Collection	2	5%
Art	7	18%
Exchange	12	32%
Aggregator	4	11%

Table 25: distribution of marketplaces supporting ETH by type

The most popular type of NFT marketplace that supports the Ethereum blockchain are the ones that are part of a cryptocurrency exchange, with the 32% of the totality. The second most popular category is the open marketplace that does not deal with a particular niche, but are open to sell any kind of NFTs, with the 24%. The third place is taken by the art marketplace that sell exclusive art NFTs, that take 18% of the totality.

Since Ethereum is the most popular cryptocurrency after Bitcoin, every major cryptocurrency exchange must support it, therefore it is included in the NFT marketplaces.

When open marketplaces support many blockchains, Ethereum is usually between one of the supported ones.

Art and gaming marketplaces are usually lean to other blockchains, that are less popular but offer some advantages such as lower gas fees or faster transaction.

BNB Chain

Binance's proprietary chain is an Ethereum virtual machine, used as an alternative to Ethereum. This is more efficient than the latter's since it uses Proof-of-Staked-Authority (PoSA) that does not need heavy mining equipment.

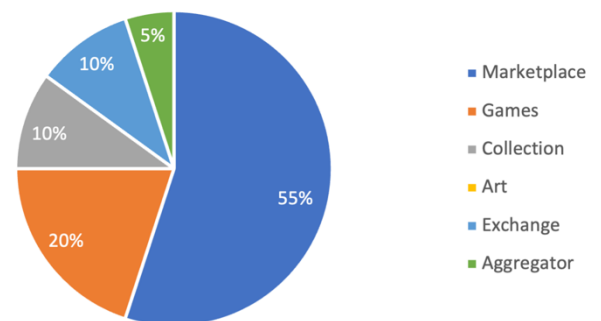| Type	Marketplaces	Percentage
Marketplace	11	55%
Games	4	20%
Collection	2	10%
Art	0	0%
Exchange	2	10%
Aggregator	1	5%

Table 26: distribution of marketplaces supporting BNB by type

Open marketplaces that support many blockchain tend to support BNB chain, since it is considered a valid alternative to Ethereum. For this reason, this is the most popular type, that takes more than 50% of the marketplaces that support BNB Chain.

The second most popular category of marketplaces are the ones that deal with gaming, including Axie Marketplace and Mobox. The rest of the marketplaces are split between the types of collection, exchange and aggregator.

NFT marketplace that deal with art do not support BNB chain, since other blockchain are preferred in this industry.

Polygon

Polygon is a blockchain platform that enables blockchain networks to connect and scale. It aims to create a multi-chain blockchain ecosystem compatible with Ethereum, and like this uses proof-of-stake consensus mechanism.

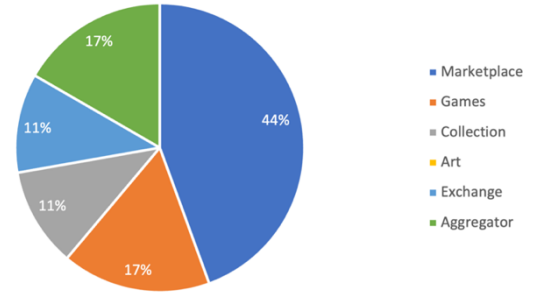| Type	Marketplaces	Percentage
Marketplace	8	44%
Games	3	17%
Collection	2	11%
Art	0	0%
Exchange	2	11%
Aggregator	3	17%

Table 27: distribution of marketplaces supporting Polygon by type

The most popular type of marketplace on Polygon is the general open marketplace, with 44% of the marketplaces covered. It is compatible with OpenSea for example. Then, it is used in every industry, such as gaming NFT like Aavegotchi, or aggregator like Gem, but it is not used in any art marketplaces.

Solana

Solana is a great blockchain for users give a lot of importance to cost and scalability. It is similar to Ethereum but uses proof-of-history and delegated proof-of-stake consensus mechanism and offer faster transactions speed than its competitors at a fraction of the cost.

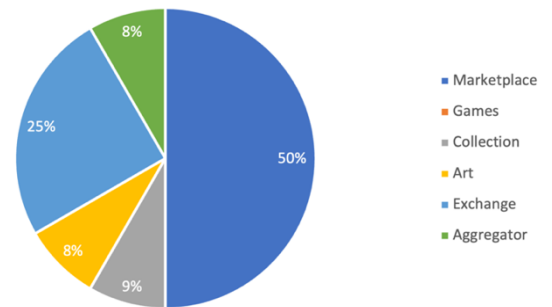| Type	Marketplaces	Percentage
Marketplace	6	50%
Games	0	0%
Collection	1	9%
Art	1	8%
Exchange	3	25%
Aggregator	1	8%

Table 28: distribution of marketplaces supporting Solana by type

Exactly half of the marketplaces analyzed that support Solana are general marketplaces that sell NFTs of any kind. The 25% of marketplaces are marketplaces that belong to a cryptocurrency exchange, while the rest is split between the other categories excluding the gaming one.

4.3.1.1 Distribution of types by blockchain

In this section there will be the description of the blockchains for each category of marketplaces, in order to find out which are the blockchains that are supported the most for every type of marketplace.

Art

Blockchain	Art	Percentage
Ethereum	7	54%
Tezos	4	31%
Solana	1	8%
Waves	1	8%

*Table 29: distribution of blockchains in art marketplaces*
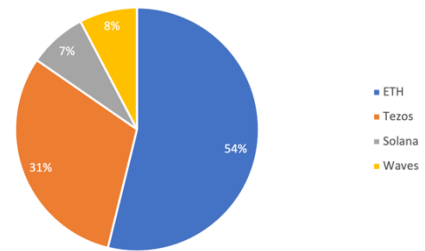
The graph shows that the 54% of NFT marketplaces that deals with art support the Ethereum blockchain. Then, the 31% of these NFT marketplaces support exclusively Tezos, a blockchain that can upgrade without having to interrupt services to its users and attempts to build the decision-making process into the network of users itself. Then the rest of the percentage is divided between the blockchain Solana and Waves, which offer quick services for a low price.

Gaming

Blockchain	Gaming	Percentage
Ethereum	4	21%
BNB	4	21%
Polygon	3	16%
Immutable X	2	10%
Others	6	32%

Table 30: distribution of blockchains in gaming marketplaces
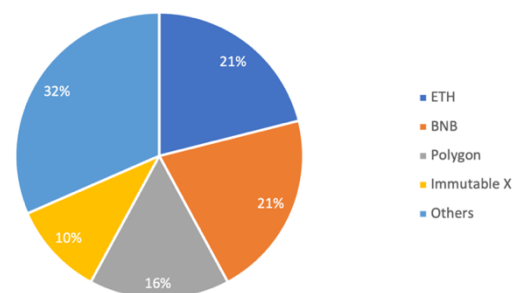
The figure shows that the gaming industry is covered most by the three popular blockchain networks: Ethereum, BNB Chain and Polygon, which take respectively the 21% the 21% and 16% of the gaming NFT marketplaces. The rest of the NFT marketplaces are supported by other blockchain, but one to notice is Immutable X, a scaling solution designed with Layer 2 technology that's built on Ethereum blockchain, providing scalability, almost zero gas fees and the ability to launch projects quickly.

Aggregator

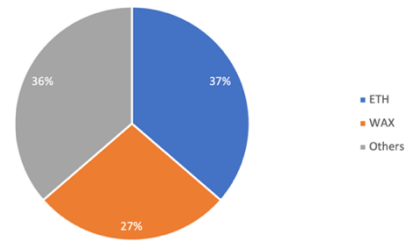| Blockchain	Aggregator	Percentage
Ethereum	4	36%
WAX	3	28%
Others	4	36%

Table 31: distribution of blockchains in aggregator marketplaces

In the marketplaces that aggregates NFT from other platforms, Ethereum and WAX, a blockchain designed to make e-commerce transactions faster, easier and safer, are the blockchains that are supported the most.

Exchange

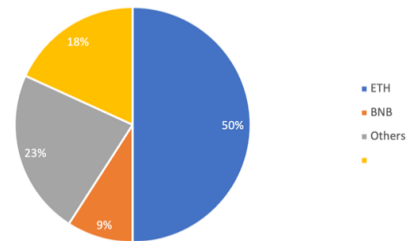| Blockchain	Exchange	Percentage
Ethereum	11	50%
BNB	2	9%
Others	5	23%
Many	4	18%

Table 32: distribution of blockchains in marketplaces that belong to crypto exchanges

Exactly half of NFT marketplaces analyzed that belong to a cryptocurrency exchange supports exclusively Ethereum. The 18% support many different blockchains, like the most popular ones like Crypto.com and Binance. The second most popular blockchain supported is BNB Chain, and the 23% of the marketplaces supports other minor blockchains.

Collection

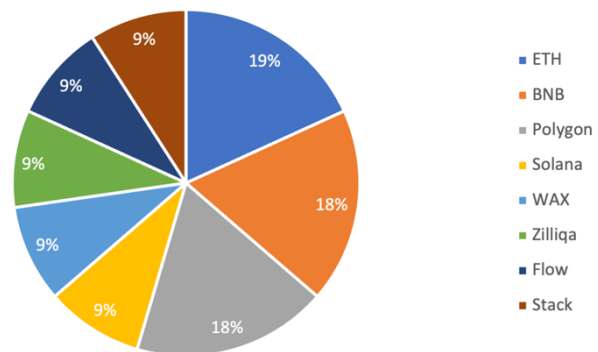| Blockchain	Collection	Percentage
Ethereum	2	20%
BNB	2	20%
Polygon	2	20%
Solana	1	10%
WAX	1	10%
Zilliqa	1	10%
Flow	1	10%
Stack	1	10%

Table 33: distribution of blockchains in NFT collections

The most popular blockchains in NFT collections are Ethereum, BNB Chain and Polygon, each sharing the 18% of the NFT collections. The rest is equally divided between other minor blockchains, including Solana and WAX.

Marketplace

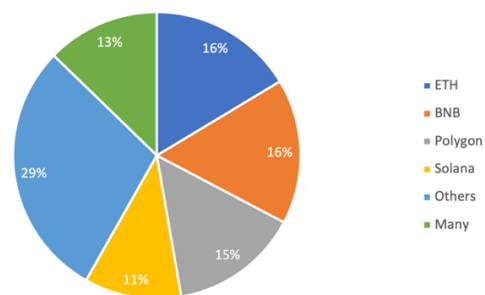| Blockchain	Marketplace	Percentage
ETH	9	19%
BNB	9	19%
Polygon	8	17%
Solana	6	12%
Others	16	29%
Many	7	13%

Table 34: distribution of blockchains in general marketplaces

In marketplaces that sell any kind of NFT, Ethereum and BNB appear to be the most popular blockchains, with the 19% of the marketplaces each. The third and fourth NFT marketplaces are Polygon and Solana, with respectively the 17% and 12% of the marketplaces. The 7% of the NFT marketplaces support many different blockchain, while the rest support other single blockchains.

4.3.2 Governance

The NFT marketplaces in the report have been distinguished between centralized, where the decision-making process is exclusive to the organization that owns the platform, and decentralized, where the users and customers can influence the decision regarding changes in the platform. This is made possible through different mechanics, such as a governance token or a voting system in the platform or in social networks.

Governance	Marketplaces	Volume sales	Percentage
Centralized	50	$38.108.859.981	73,48%
Decentralized	50	$13.752.809.435	26,52%

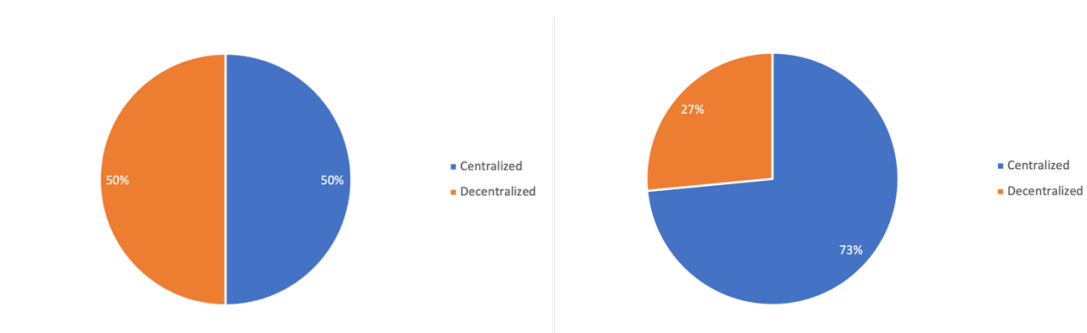*Table 35: distribution of governance in NFT marketplaces*

Figure 21: distribution of NFT marketplaces and volume sales by governance type

In the report analyzed, exactly half of the marketplace analyzed have a centralized governance, while the other have a decentralized governance. However, the centralized marketplaces hold the 73% of the total volume sales while the decentralized ones only the 27% of it.

4.3.3 Proprietary token

Many NFT marketplaces have introduced a digital token proprietary of the platform for many different reasons and can have many functionalities, such as governance token or utility tokens. These are widespread in the public through events called airdrop and are given either to selected users that satisfy certain requirements or to every customer.

Token	Marketplaces
Yes	67
No	33

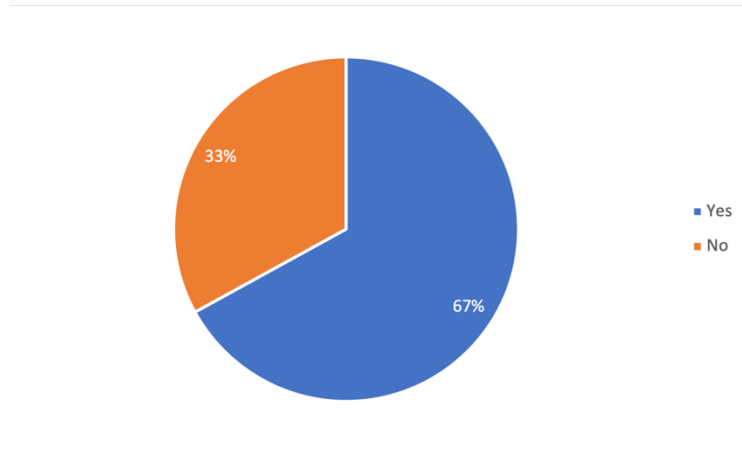*Table 36: distribution of NFT marketplaces by proprietary token*

Figure 22: distribution of NFT marketplaces by proprietary token

The figure shows that 67% of the analyzed market has introduced a proprietary token in their platform.

Token	Centralized		Decentralized	
	Marketplaces	%	Marketplaces	%
Yes	23	46	44	88
No	27	54	6	12

Table 37: distribution of NFT marketplaces by proprietary token in centralized and decentralized governance
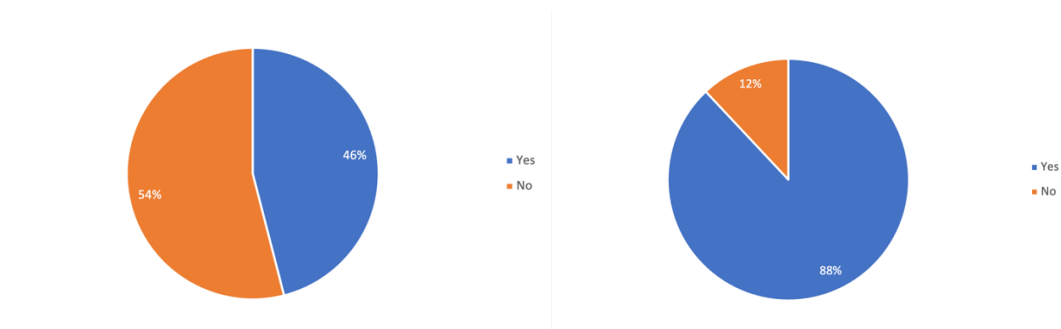

Figure 23: distribution of NFT marketplaces by proprietary token in centralized and decentralized governance

The 46% of the centralized marketplaces have a proprietary token, which however is not a governance token since it does not give any right to vote but can give other benefits, like claiming rewards in games or have an early access to a new collection published in the platform.

The majority of decentralized marketplace have a proprietary token, that are governance token since are given to the users in order to allow the owners to participate in the vote mechanism. The decentralized marketplaces who do not offer a proprietary

token make this possible through other mechanism, such as tickets made for this purpose or platforms made for this purpose.

4.3.4 Data savings storage

NFT marketplaces have to save many data regarding the users, the NFT's metadata and the transactions. All of these can be saved in different storages, by choice of different design. These data can whether be saved on-chain, so directly on the smart contract, off-chain, on an external storage, or can be partially saved off-chain and partially saved on-chain.

Transactions	Centralized		Decentralized		Total	
Off-chain	11	22%	4	8%	15	15%
On-chain	9	18%	21	42%	30	30%
Both	30	60%	25	50%	55	55%

Table 38: distribution of transactions in centralized and decentralized NFT marketplaces
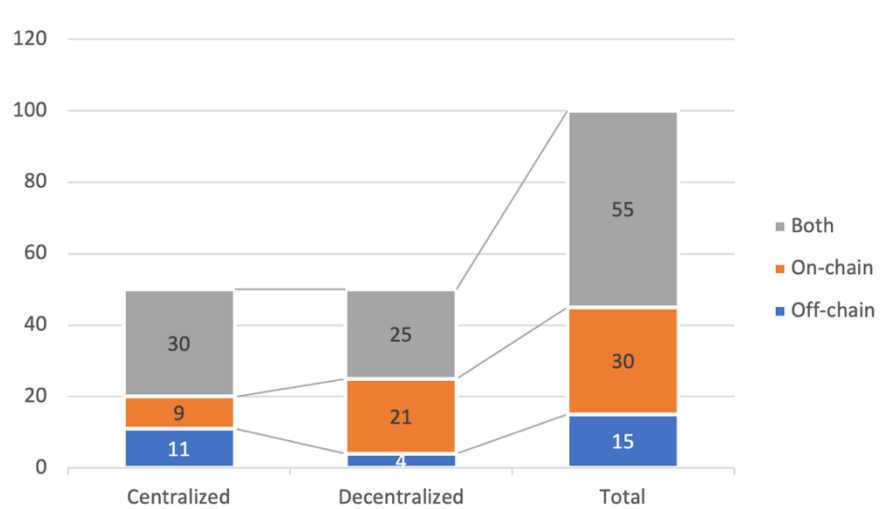

Figure 24: distribution of transactions in centralized and decentralized NFT marketplaces

The figure above shows that 55% of NFT marketplaces save data both on-chain and off-chain. This means that part of the metadata of NFTs are stored in a medium storage, while the critical data are stored on-chain. Then, 30% of the NFT marketplaces save transactions on-chain while 15% save them totally off-chain.

In NFT marketplaces where the governance is centralized there is a higher trend to save data off-chain than in the ones where the governance is decentralized, where 42% of the marketplaces save data totally on-chain. However, the method which is used the most is

always the hybrid one, in which critical data are saved on-chain and others are saved off-chain.

4.3.5 Standard

Most of the NFT marketplaces support many protocols, but the most popular ones are the standard of the Ethereum blockchain, meaning ERC-20, used for tokens, ERC-721, used for NFTs and ERC-1155, which adds some functionalities to the NFTs. All of these are explained in the previous chapter about the standards.

Standard	Marketplaces
ERC-20	67
ERC-721	72
ERC-1155	54
Other	9

Table 39: distribution of marketplaces by standard
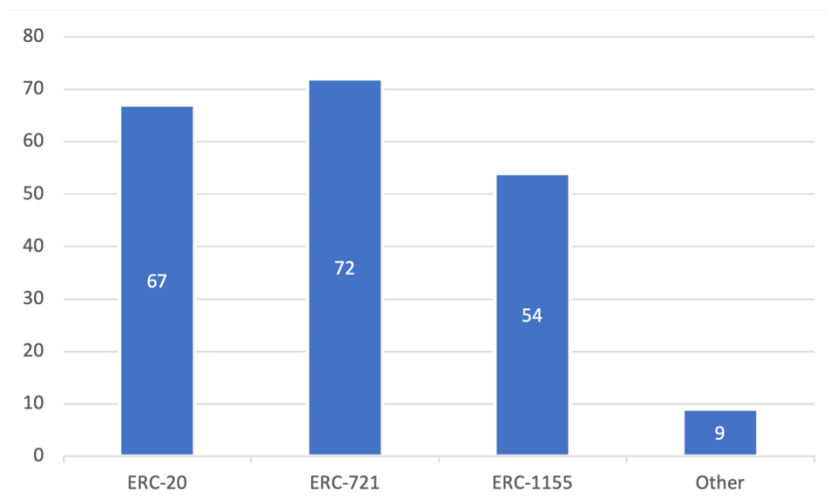
Figure 25: distribution of NFT marketplaces by standard

The 67% of the marketplaces support ERC-20 (Ethereum Request for Comment). These use this protocol to have an integrated token in the platform, which can be used to mint or buy NFTs. The most common protocol used is ERC-721, necessary to support NFTs, supported by the 72% of the marketplaces. Then, later in 2019 the most advanced ERC-1155 has spread in the 54% of the marketplaces analyzed.

5. Discussion and conclusion

The primary results of the empirical analysis have been summarized in this last chapter in order to reach the study's goal and respond to its research questions. After this review, the implications for NFT marketplaces, users, sellers, and enthusiasts have been discussed, and the research's limitations have been addressed by making suggestions for relevant, future studies that could be done.

5.1 Discussion and main findings

In the introduction of this thesis, a review of the literature has been conducted, describing the main characteristics of the NFTs and the technology that lays under it, the blockchain. In particular, after a description of the history, the technical components have been described, including the standards, the programming languages, the transactions, the consensus mechanism, the storage and a comparison between the most popular blockchains. Subsequently, a guide to create and deploy a smart contract is presented. Finally, the NFT marketplaces have been clustered and classified in different types, depending on their purpose.

The main problems and limitations that are in the NFT marketplaces have been addressed, proposing the various advantages and disadvantages of the technological solution provided by each platform. Later, there has been presented a description of the main parts that differentiate one marketplace from the other, so the wallets, the purchase method, the governance, the transaction costs and the token.

Later, the focus moved to the business side implementation of NFT marketplaces, and the new technologies have been identified capable of driving the directions of development of the blockchain used.

On this regard, there have been described the main type of revenues of marketplaces and their choices on the fees applied to each transaction, both acquired from the marketplace itself and the percentage that was destined to be sent to the original creator of the NFT. Many NFT marketplaces have been investigated whether from research and interviews, and the importance of the community has been explained.

Regarding the technological analysis, the different classification of blockchains, standards and tokens that have been made in the literature have been outlined.

Finally, the main gaps found in the literature have been evidenced, which are summarized below:

- In the literature very few analyses make a classification that concerns only the NFT marketplaces, but usually comprehend cryptocurrencies exchanges as well.
- Websites that make data analysis of the NFT market deal with certain categories. They exclude NFT marketplaces that belong to exchange or deal with on-chain activities that happen only on a single blockchain and not on multiple ones.
- Various papers describe the advantages of the NFTs and blockchain technologies, but there is a lack of information about the limits of the platforms that sell them.
- The tokens have been analyzed and classified from a technical point of view, but the role that the tokens have in the platform of the NFT marketplaces has not been studied, nor what they bring. In addition, there is no empirical analysis that shows which types of tokens are used most by NFT marketplaces.
- Although technical elements have traditionally received more attention in the literature than business aspects, consensus mechanisms have received minimal attention. There is not enough empirical research to indicate which consensus mechanisms that have been created by new blockchain platforms are utilized the most, how many of them have used already existing consensus mechanisms, and how many have created entirely new ones.

The review of the literature has underlined the disruptive potential of NFT marketplaces and has highlighted the interest of the scientific community towards them. Several studies have examined the problem from a technological perspective and given an overview of the available technology in this field.

However, the NFT ecosystem is continuously changing and in 2022 the market of the NFTs declined after the initial hype that followed their rise in popularity. Many NFTs fell sharply in value, prompting some to question their long-term viability. This was due to a combination of factors, but primarily because on the sell-off in digital assets between

May 2022 and August 2022. Many NFT marketplaces have gone bankrupt, but this led to important changes in the policies and fees of the various platforms.

In this regard, the literature has identified the main trends in the ecosystem and the NFT marketplaces that could take the role of possible leaders the market, they have therefore been considered strategic players to study in the implementation of NFT marketplace in the business.

The empirical analysis that has been performed on NFT marketplaces had precisely the objective of providing information on the technical choices undertaken, with the aim of identifying the technical patterns common to successful platforms.

The results of the empirical analysis are summarized below.

Overview of NFT marketplaces

The analysis of a database of NFT marketplaces provides an overview of the platforms in different sectors. The basis of the analysis was a database of 100 NFT marketplaces raised a total of $51.861.669.416 USD until the period of analysis.

Total marketplaces	Volume sales	Average	Median
100 marketplaces	50 billion	624 million	10 million

Table 40: total, average and median of volume sales of NFT marketplaces

Volume sales	Marketplaces		Volume sales	
Over 1 billion	6	7%	$44.139.695.280	85%
Between 100 mln & 1 bln	17	20%	$6.989.493.742	14%
Between 10 mln & 100 mln	19	23%	641.774.451	1%
Between 1 mln & 10 mln	24	30%	85.006.428	<1%
Under 1 mln	17	20%	5.699.515	<1%

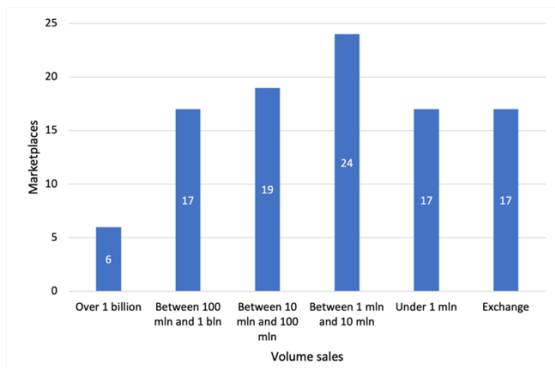*Table 41: distribution of NFT marketplaces by volume sales*

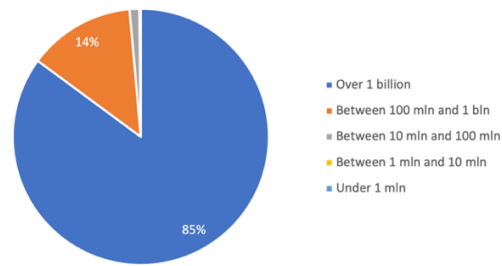*Figure 1: distribution of NFT marketplaces by volume sales*   *Figure 2: distribution of volume sales by cluster*

The 17% of the marketplaces have been excluded from the collection of data regarding volume sales, since they belong to a cryptocurrency exchange, and it was impossible to distinguish their sales coming from the NFT marketplaces from the ones coming from cryptocurrency platform.

From this first overview it has emerged that the market is dominated by small group of marketplaces, the ones that have the highest volume sale, over $1 billion USD. Only 6 NFT marketplaces have reached a total volume sale of over $1 billion, more specifically OpenSea, Axie Marketplace, CryptoPunks, MagicEden, Blur and LooksRare, for which however most of the volume sales has been considered as wash trading[49].

The most popular NFT marketplace is OpenSea, the open marketplace funded in 2017, which was one of the first to believe in the standard ERC-721 and created a way to pass the cost of minting new NFTs. Axie marketplace is the marketplace of Axie Infinity, the most popular P2E crypto game. CryptoPunks is a collection launched in 2017 made of 10.000 tokens sold for high prices. Magic Eden is the largest marketplace on Solana. Blur is a new NFT marketplace and aggregator launched on late 2022, which is radically changing the market by offering zero platform fees and optional royalties, making it cheaper than rivals. Sudoswap is the first NFT automated market maker that exploits liquidity pools. There are many companies competing with Opensea, but some volume sales are not sure to be used as an index of comparison, since many platforms such as LooksRare are suspected of "wash trading", an activity that incentive users to make transactions between their wallets to earn more rewards.

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[49] According to analytics from CryptoSlam

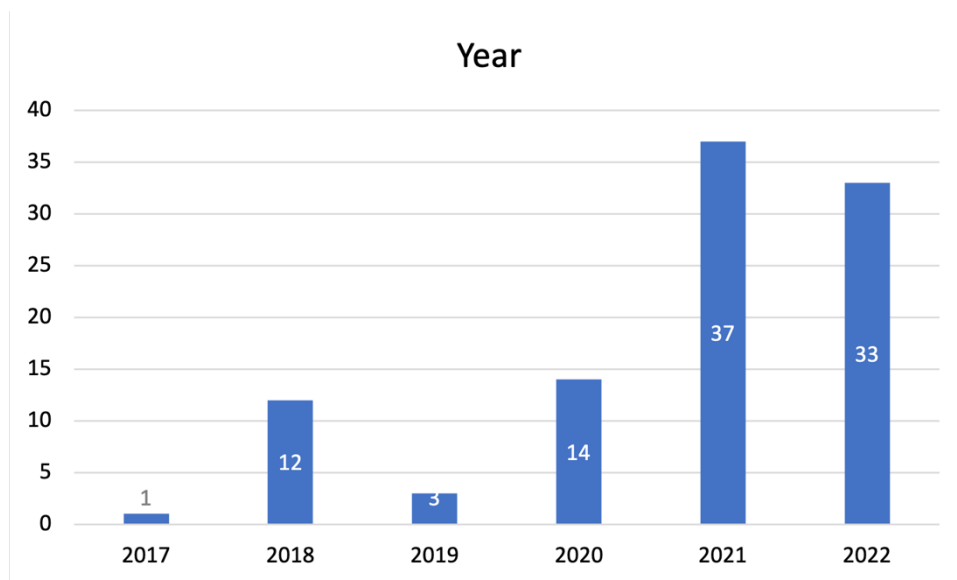**Distribution of NFT marketplaces over years**

Year

Figure 26: distribution of NFT marketplaces over years

The distribution of the NFT marketplaces over years highlights a strong growth in the last two years of analysis. Indeed, the NFTs became very popular during the two years 2020-2021, when the cryptocurrency bull market raised gave a lot of opportunities investing in NFTs. The majority of NFT marketplaces have launched after 2020. In 2021 approximately $41 billion USD worth of crypto was spent on NFT marketplaces.

However, it was in 2017 that NFT went in public. Indeed, in that year has happened the release of CryptoPunks, which introduced more than 10.000 different characters, and CryptoKitties, which introduced the concept of gaming in NFTs, helped shape up the NFT landscape. Then between the years 2018 and 2020 NFTs gradually started gaining public's attention, primarily due to NFT gaming and metaverse projects. The pandemic definitely played a key role in the rise of NFTs, because when the physical world was restricted, the place where people found more excitement was the digital one, which experienced a boom. Media reported news about an NFT digital artwork raked in $69 millions USD (making it the third most expensive art piece ever sold from a living artist), the price of a single Bitcoin of $60,000 USD for which this topic became so popular to be considered the term of 2021. This led the NFT market to grow by more than 26000% in 2021 compared to 2020.

Finally, in 2022, despite month of declining sales and falling prices during the second half of the year, the overall NFT marketplaces founded nearly matched the 2021 peak, like the NFT sales volume.[50] Indeed, the NFT market generated around $24.7 billion USD worth of organic trading volume in 2022 across blockchain platforms and marketplaces. That's a slight dip from the $25.1 billion USD total recorded in 2021 as the NFT market surged in activity and interest as tokenized collectible first became more than a niche interest. Dappradar data excludes trades that are suspected to be wash trades, or trades that have been manipulated in some way. The crypto market lost significant value over the course of the year, with losses accelerating in May amid the collapse of Terra's LUNA and UST. The so-called crypto winter was then exacerbated by the downfall of crypto exchange FTX and the resulting industry contagion, impacting crypto prices further. The NFT market followed a similar progression throughout the year. Sales surged in January as 2022's momentum carried into the new year, as top marketplace OpenSea alone registered a record month with $5 billion in trading volume. Trading volume dipped in the months after, but then the massive late April launch of NFT land plots or Yuga Labs' "Otherside" drove OpenSea to a single-day record for trading volume. However, crypto prices collapsed in May, so did NFT trading momentum, with prices falling sharply as a result. Monthly volume fell from nearly $3.3 billion in May to just over $1 billion in June, and the market hasn't topped the $1 billion mark in the months since. Ethereum's Bored Ape Yacht Club was 2022's top selling NFT project[51], with nearly $1.6 billion worth of trading volume. In December the volume had a slight whimper: OpenSea remained the leading marketplace for NFT trades, with Blur after it, a new rival that incentivized NFT trades with the promise of upcoming token rewards, while Solana blockchain continued it up-and-down pattern.

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[50] According to Dappradar
[51] According to CryptoSlam

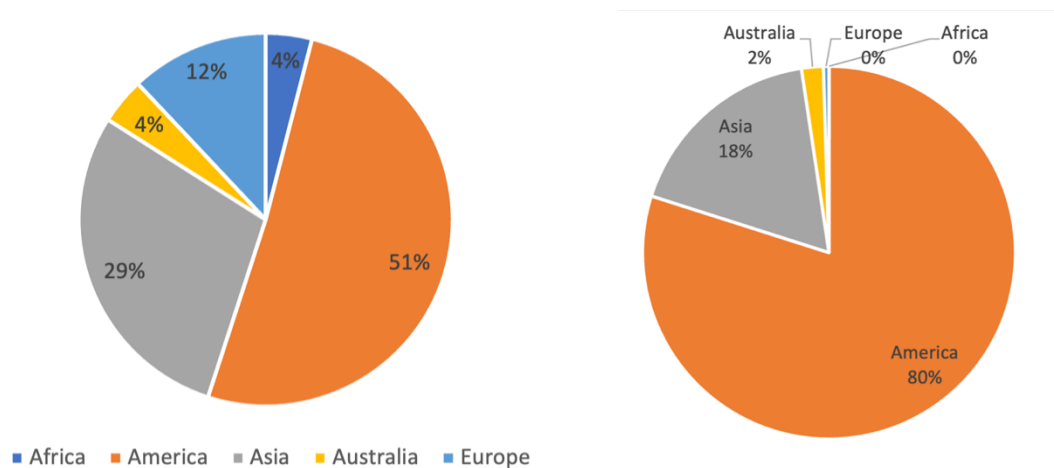**Geographical distribution of NFT marketplaces**

Figure 27: distribution of NFT marketplaces and volume sales by continent

The results of the geographical analysis showed clear differences in the presence of NFT marketplaces across different geographical areas. America is one of the most popular continents because it is one of the most valuable markets, as one of the biggest sources of revenue. American consumers have the most disposable income to invest and purchase in digital technologies such as cryptocurrency and NFTs. Instead, Asia is the continent that has seen the biggest rise in a technological point of view, as Asian countries have made considerable investments to progress in recent years. In Europe, the NFT market witnessed significant growth recently.

Also looking at the volume sales, America is dominating the market with 80% of the all-time volume sale analyzed in these 5 years. Asia is taking the 18% while the rest is divided between all the other continents of the world.

This geographical analysis has evidenced how the location of an NFT marketplace is an important factor for its growth potential. Indeed, the owner of the platform have to consider the regulation imposed by the country he is living in, since actions like the introduction of a token could cause some fines to pay. Moreover, the NFTs and the cryptocurrencies are still technologies that are relatively new, and not every country in the world has already written a complete regulation.

Regarding this, United Stated have not specified yet a regulation for NFTs, but it turns on how they are classified, depending on the particular rights and attributes associated with them. In China cryptocurrencies are currently banned, but individuals can sell or buy NFTs, and the country issued an initiative regarding prevention of NFT related financial risks called the Initiative. In the European Union there is no specific regulation or legal definition of NFTs and no harmonized regulatory regime across the member states. The European Commission has published a Markets in Crypto-Assets Regulation (MiCA) which specifically excludes NFTs from its scope. When NFTs result in sales of more than €10.000, standard anti-money laundering regulations (AML) are applied, and the seller must meet due diligence requirements, and follow the guidelines for the proper transaction records. Every European nation has its own regulations. In Italy there are no specific laws regulating NFTs, which might qualify as "investment products" as per Article 1, paragraph 1, letter u) of the Italian Consolidated Financial Act, this implied additional requirements on the seller such as being licensed.

It should be remembered that not all platforms selling NFTs verify the identity of the seller. Finally, in some countries a high percentage of people already own some cryptocurrencies while in others it is not yet a popular concept, and this can influence the demand of the marketplaces.

Types of marketplaces

Type	Marketplaces		Volume sales [$]	
Aggregator	7	7,00%	1.427.421.336	2,75%
Art	13	13,00%	1.610.028.229	3,10%
Collection	8	8,00%	4.025.628.530	7,76%
Exchange	17	17,00%	-	-
Games	16	16,00%	4.966.722.830	9,58%
Marketplace	39	39,00%	39.831.868.491	76,80%

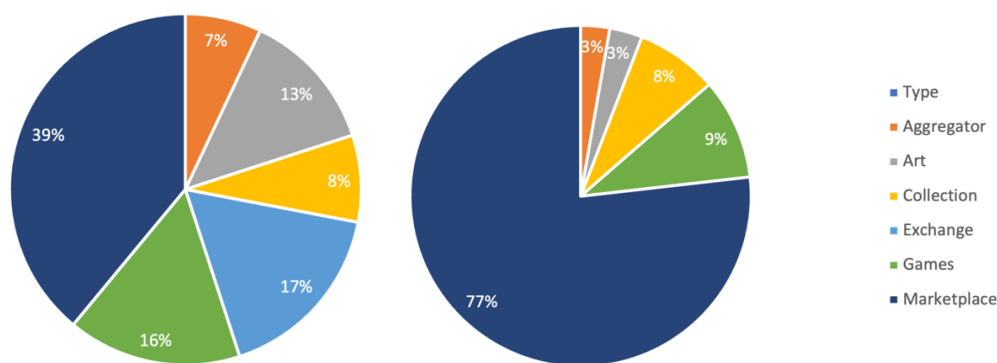*Table 42: distribution of NFT marketplaces and volume sales by type*

Figure 28: distribution of NFT marketplaces and volume sales by type

The classification of the marketplaces shows that with the 39% of the marketplaces analyzed, the most popular type of marketplace is the open marketplace, where anyone can mint and sell NFTs. On these marketplaces, like OpenSea and Rarible, there is no need to apply and get accepted, creators just connect to a wallet and mint the NFTs. Moreover, these are more versatile, since in this type of platform any type of NFTs is sold, so users of various targets are satisfied at the same time. Finally, these NFT marketplaces usually function as secondary marketplaces of NFT collections coming from other websites.

The only downside is the quality of NFTs, which could be higher or addressed better to the niche of people in marketplaces belonging to the category of art, which takes the 13% of the market of the report. Here the marketplace is more "curated", meaning that the platform determines which NFTs are allowed to be minted, posted and sold on directly is marketplace.

However, the second most popular category are the proprietary marketplace, that offer only NFTs created by the marketplace operator and do not facilitate the sale or display of other NFTs. Two categories belong to this type of marketplace, the gaming, which is having so much success thanks to games like Axie Infinity, and the collections like Ape Bored Yacht.

It has to be noted that volume sales of marketplaces belonging to exchange are not provided in this report.

Aggregators are a new type of marketplaces which at the time of the analysis is still in the beginning of their cycle, but platforms like Blur, sudoswap and Uniswap are growing in popularity very fast and could radically change the market. Aggregators allow users to avoid browsing NFTs through different platforms and provide a smooth user experience with fast trading execution and broad selection of non-fungible tokens.

Commission fee

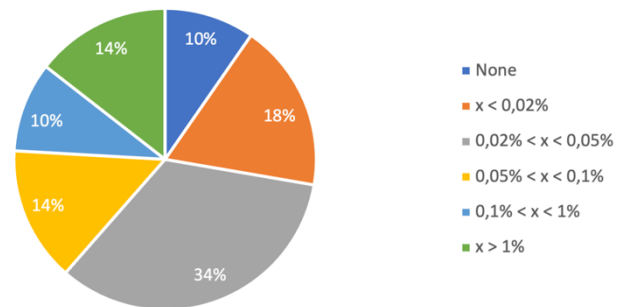| Commission fee	Marketplaces	Percentage
None	8	10%
x < 0,02%	15	18%
0,02% < x < 0,05%	28	34%
0,05% < x < 0,1%	12	14%
0,1% < x < 1%	8	10%
x > 1%	12	14%

Table 43: distribution of commission fee of NFT marketplaces

The majority of NFT marketplaces have a commission fee that is lower than 1%. At the beginning, many marketplaces have set a commission fee of 2,5%, taking inspiration by OpenSea. However, the market has imposed a competition to lower these in order to incentive the public to join them. In February 2023, the top marketplace OpenSea's policy shift stems from competition with popular zero-fee marketplace Blur and decided to set 0% fees for a limited time. This event led to a general trend in the market.

Royalty fee

Royalty fee	Marketplaces	Percentage
None	7	10%
Fixed	12	16%
Variable	54	74%
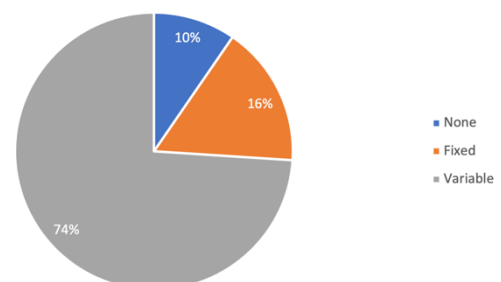
Table 44: distribution of royalty fees in NFT marketplaces

The majority of the marketplaces let the creator set the royalty fee right after the process of minting the NFT, giving them some maximum threshold that usually reach 10%, but in some cases can be set up to 40% of the transaction. In other cases, it can be chosen by the marketplace but can change based on the number of transactions that the digital piece has been subjected to. For example, in the platform SuperRare the artist

gets 85% of the sale price on the primary sale, and then he gets 10% of the transaction on secondary sales.

Finally, in the end of 2022 a new trend has involved a few marketplaces such as X2Y2, Magic Eden and LooksRare to set the royalty fees as optional. In this case, buyers have the option of implementing the smart contract for royalty payments and can choose whether to pay them and in positive case to set them as they like. Some marketplaces set a minimum threshold of 0,5%, like the new OpenSea's concurrent Blur, others have decided to share around 25% of their protocol fees with creators to alleviate the effect. However, many artists have started to blacklist the NFT marketplaces that evade royalties.

OpenSea has taken a hardline stance in the debate over creator royalties, launching a royalty enforcement tool in November that allows new collections listed on the site to delegate royalties on-chain. This tool also blocks these collections from being resold on marketplaces that don't enforce royalties, like X2Y2 and Blur.[52]

In January 2023 Blur found a loophole in OpenSea's blocklist, allowing collections that enforced royalties on OpenSea to uphold their percentages on Blur. Indeed, it created a new marketplace on Seaport, a protocol that OpenSea released in May 2022, which since is not included in the original blocklist, can list collections with enforced royalties on the marketplace.

Blur in s blog encouraged its users to blocklist OpenSea in order for creators to collect full royalties on its platform. In February 2023 OpenSea, to contrast its competitors, has decided to move to optional creator earning (0.5% min) for all collections without on-chain enforcement (old and new).[53]

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[52] Cam Thompson (2023) – "OpenSea Goes Zero-Fee, Creator Royalties Optional" retrieved on 10/03/2023 at CoinDesk: [https://www.coindesk.com/web3/2023/02/17/opensea-goes-zero-fee-creator-royalties-optional/]

[53] As stated by OpenSea twitter account:
[https://twitter.com/opensea/status/1626682043655507969?ref_src=twsrc%5Etfw%7Ctwcamp%5Etweet embed%7Ctwterm%5E1626682043655507969%7Ctwgr%5E772bb444616e1d10d7df8e067c95379c48cdd0 94%7Ctwcon%5Es1_&ref_url=https%3A%2F%2Fwww.coindesk.com%2Fweb3%2F2023%2F02%2F17%2Fo pensea-goes-zero-fee-creator-royalties-optional%2F]

Purchase methods

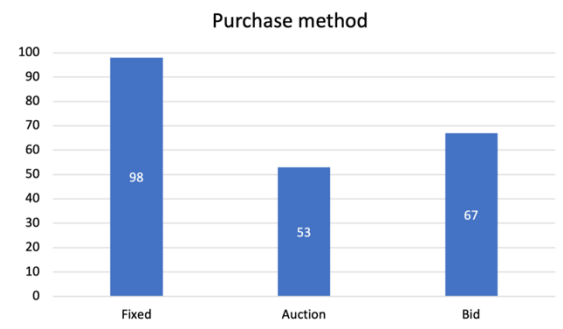| Purchase method	Marketplaces
Fixed	98%
Auction	53%
Bid	67%

Table 45: distribution of purchase methods adopted by NFT marketplaces

Almost all marketplaces offer the possibility to buy NFT at a fixed price immediately, and the majority allow the two other purchase methods as well, auction and bids. In this way, a marketplace can give its customers, both buyers and sellers, more ways to make a transaction and this can lead to a higher popularity. In marketplaces that sell only proprietary NFTs that are made by the platform, it is not usual to implement auctions, which are excluded from almost half of the marketplace for this reason.

A few marketplaces, 4 to be precise, offer a fourth purchase method in which customers can purchase a "mystery box" that contains some randomized NFT that can have a higher or lower value than the price that the user paid for it. This is used mainly in NFT marketplaces that deal with gaming but this has not been considered as one of the main purchase methods in this report.

Regarding the possibility to buy NFTs with a credit card, this is an option spreading in the majority of the marketplaces through platforms such as MoonPay, Stripe and Switch, which simplify in a considerable way the purchase of FNTs.

NFT minting

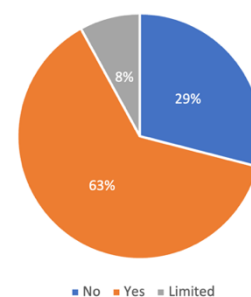| Mint NFT	Marketplaces
No	29
Yes	63
Limited	8

Table 46: distribution of possibility of NFT minting in NFT marketplaces

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More than the 70% of the marketplaces give to its users the chance to mint an NFT directly on their platforms, by uploading their file and paying a gas fee, without having to learn all the technical details, since the platform will handle all the technical part. This is an important opportunity given to the customers, and marketplaces that do not allow this usually only sell proprietary NFTs like in game assets or digital pieces born from the collaboration with artists.

Blockchain platforms

Blockchain	Marketplaces	Volume of sales	Percentage
Many blockchains	21	45.026.294.615	72,71
Ethereum	24	4.949.901.478	7,9933
BNB Chain	8	112.017.780	0,1809
Solana	7	3.829.690.681	6,1843
WAX	6	3.084.970	0,005
Tezos	6	739.434.155	1,1941
Others	27	7.265.356.356	11,732

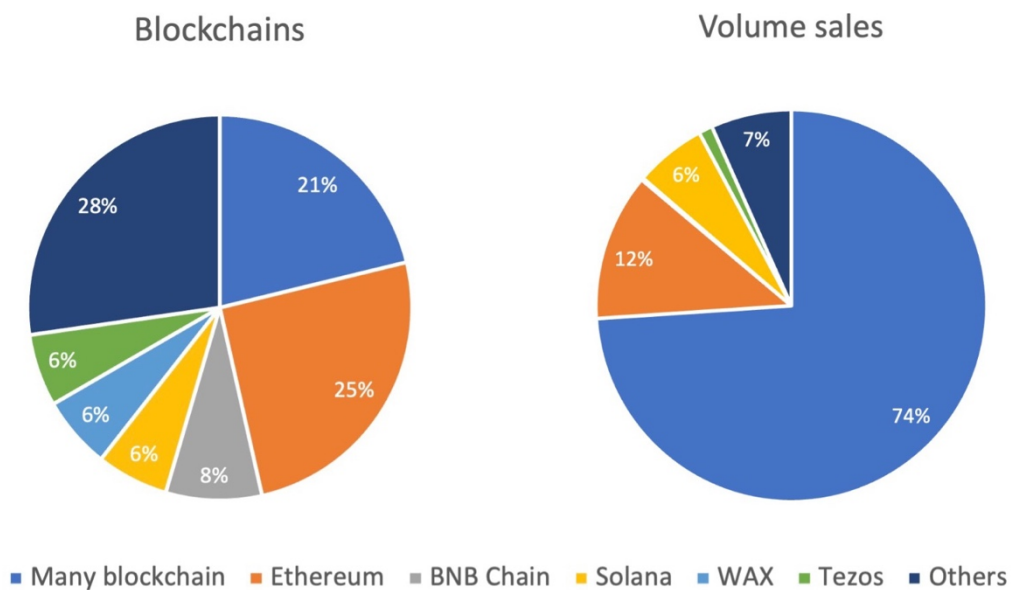*Table 47: distribution of NFT marketplaces by blockchain*

Figure 29: distribution of NFT marketplaces and volume sales by blockchain

Many NFT marketplaces do not support a single blockchain network, but they interface with various blockchains to provide their service. This is the case of models of open marketplaces like OpenSea, or marketplaces that belong to cryptocurrencies exchanges.

The blockchain that is supported by most of the NFT marketplaces is Ethereum, which has always been the most popular in this sector. Then, after the Merge and the transition from Proof-of-Work to Proof-of-Stake it has gained many advantages. Despite having higher gas fees and slower transaction times than other new blockchains, it is still the leading marketplace, and many other blockchains that work as a layer 2 for Ethereum are contributing to its popularity, by enhancing its performance. However, the majority of the volume sales take place in the marketplaces that support many different blockchains, giving the users the possibility to choose between a variety of different networks. Valid alternatives to Ethereum are BNB Chain, Solana and Polygon which provide many advantages such as lower gas fees and faster transactions.

BNB Chain is an Ethereum Virtual Machine that provides more efficiency thanks to its Proof-Of-Staked-Authority (PoSA) consensus mechanism. Polygon is a blockchain that enables blockchain networks to connect and scale, being compatible with Ethereum. So it is considered a parallel blockchain (sidechain) that facilitate faster and cheaper transactions. Solana is the fastest blockchain in operations supporting over 50.000 transaction per second against the 15 transaction per second of Ethereum. Moreover, since it is permissionless, anyone can run the Solana validator and help secure the network.

Governance

Governance	Marketplaces	Volume sales	Percentage
Centralized	50	$38.108.859.981	73,48%
Decentralized	50	$13.752.809.435	26,52%

Table 48: distribution of NFT marketplaces and volume sales by governance
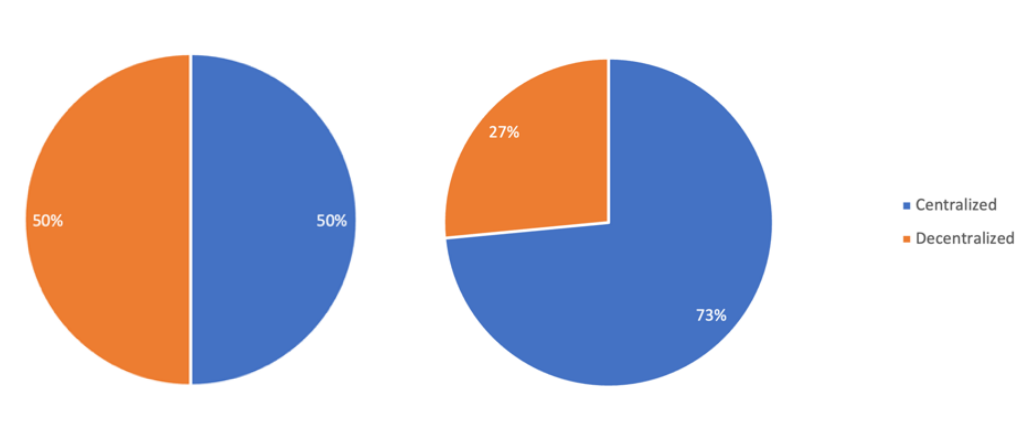
Figure 30: distribution of NFT marketplaces and volume sales by governance

Exactly half of the marketplaces analyzed have a decentralized governance, while the other have a centralized one. The latter group sees a much higher volume sales because companies like OpenSea and Axie Marketplace belong to them, and they have become very popular and are leading in the market.

Using these major marketplaces may be the status quo now, but this may not persist. The need for more neutral decentralized platforms, such as community-hosted marketplaces is clear. The economic calculus that makes NFT projects stray from hosting their own marketplaces will soon change. As new white-labeled marketplace solutions emerge, delivering a marketplace experience users enjoy, and trust will become viable. Additionally, as the initial mint revenue gets depleted, communities will increasingly begin to question the value-add of marketplaces and seek to increase their take-rate. NFT projects will also favor hosting their marketplaces to offer better, more on-brand onboarding experiences. This shift will have important implications for NFT buyers and existing NFT marketplaces.[54]

The new NFT marketplace and aggregator Blur is proving this and is radically changing the market, forcing the leader OpenSea to review and change its business model.

In a world where aggregators don't exist, every end-user needs to browse through different hotels, websites, or retail stores. Companies aggregating these resources for

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[54] Girri Palaniyapan (2023) – "NFT Marketplaces Are Centralized, and It's a Real Problem" retrieved on 20/02/23 at: [https://nftnow.com/features/nft-marketplaces-are-centralized-and-its-a-real-problem/]

the end-user, ultimately leads to productivity gain — both for the supplier and the end-user.

Similarly, in decentralized market making, protocols aggregating liquidity sources for traders into one simple UI leads to productivity gain for both liquidity suppliers and the end-user.

With market making in NFT and cryptocurrencies, centralized currently are winning. They are leading because they provide a better trading experience than decentralized counterparts. Although centralized entities clearly have risks, traders seemingly are willing to take this risk in return for the better trading experience.

Decentralized aggregators are aiming to close the gap between centralized and decentralized market by perfecting UX, resulting in the end-user profiting from an optimal trading experience, only this time in a decentralized manner.[55]

Proprietary token

Token	Centralized		Decentralized		Total
	Marketplaces	%	Marketplaces	%	Marketplaces
Yes	23	46%	44	88%	67
No	27	54%	6	12%	33

Table 49: distribution of NFT marketplaces by token in centralized and decentralized marketplaces
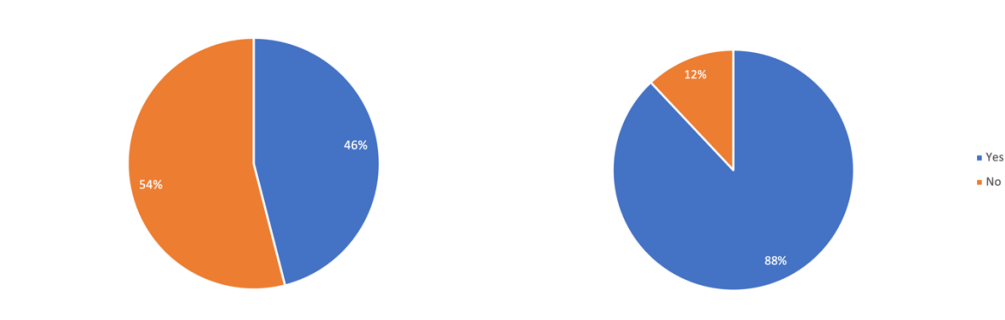

Figure 31: distribution of NFT marketplaces by token in centralized and decentralized marketplaces

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[55] Mr. Rhomboid (2022) – "Decentralized aggregation: Closing the Gap Between Centralized and Decentralized Market Making" retrieved on 22/02/23 at: [https://medium.com/coinmonks/dex-aggregation-closing-the-gap-between-centralised-and-decentralised-market-making-d05b41cdc80]

Proprietary tokens, which can be used whether as utility token or governance tokens, are introduced in the majority of the NFT marketplaces. This action can cause the owner to pay a fine, since some countries such as the United States do not allow to introduce a token without respecting some specific requirements. The proprietary tokens are much more spread in decentralized NFT marketplaces, since they are often used as governance token, to allow the owner to participate in the vote mechanism to influence the future policies' of the platform.

Data saving storage

Transactions	Centralized		Decentralized		Total	
Off-chain	11	22%	4	8%	15	15%
On-chain	9	18%	21	42%	30	30%
Both	30	60%	25	50%	55	55%

Table 50: distribution of NFT marketplaces by storage
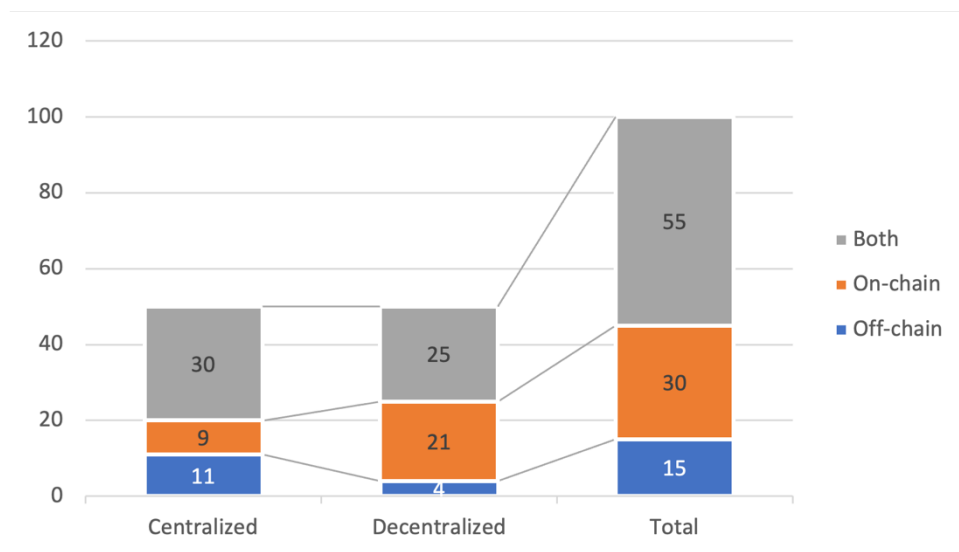
Figure 32: distribution of NFT marketplace by storage

Some marketplaces choose to save all data on-chain, so when a transaction takes place, all the data are automatically saved in decentralized ledger of the blockchain, which is updated every time a transaction occurs. This brings many advantages brought by the blockchain, including the transparency for all the users of the platform, the immutability of the data and the enhanced security. However, transactions do not take place in real time since they need to be validated and verified by the network participants first. This is the reason why some platforms save transactions off-chain, meaning that a third part

acts as a guarantee in an off-chain transaction. Layer 2 solutions play a key role in off-chain transactions. The downside to using these storage mediums is that anyone can change metadata with proper access to the server. If the server goes offline, then metadata will become unavailable, and there is the risk that the metadata could be lost in the event of data failure. One way that developers are combating these weaknesses in off-chain storage is through InterPlanetary File System (IPFS) storage.

Standard

Standard	Marketplaces
ERC-20	67
ERC-721	72
ERC-1155	54
Other	9

Table 51: distribution of NFT marketplaces by standard
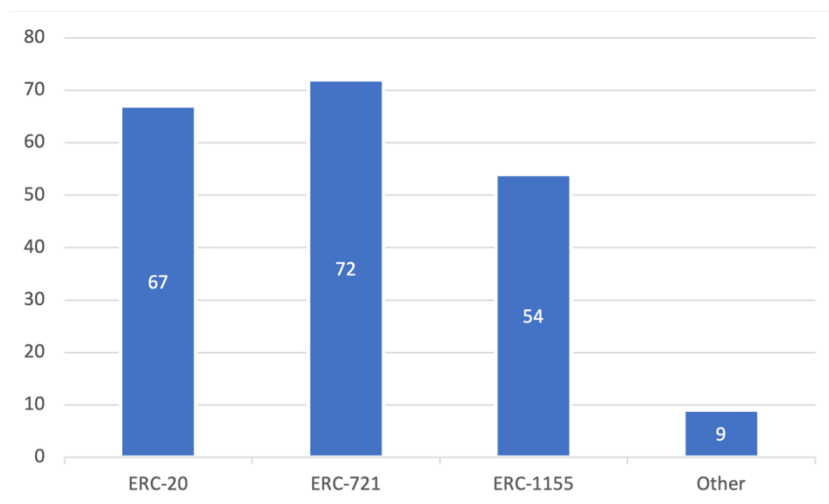
Table 52: distribution of NFT marketplaces by standard

The majority of the marketplace uses the basic standard ERC-721, while only 54% support the advanced batch functionalities of ERC-1155. The marketplaces that support the standard ERC-20 exploit it mainly to make their proprietary token work.

The only major Ethereum-based NFT marketplace that does not currently offer ERC-1155 NFTs is SuperRare. The Binance NFT marketplace is based only on Binance Smart Chain standard NFTs, while Magic Eden only offers Solana NFTs, so these marketplaces do not offer NFTs in either the ERC-721 or ERC-1155 standards.

Marketplaces that support exclusively Solana blockchain support the SPL protocol (Solana Program Library), while marketplaces that support only BNB Chain support BEP-20, BEP-721 and BEP-1155, which stand for Binance Chain Evolution Proposal.

ERC-20, ERC-721 and ERC-1155 can be bridged to other blockchains, including Hedera (Hedera Token Service), Stacks (SIP-009), Zilliqa (ZRC-2) blockchain and Ethereum Layer-2s. Ethereum layer-2 blockchains are built on top of the Ethereum Layer-1 (mainnet) blockchain and are designed to increase transaction speed while reducing gas costs while inheriting the scalability, decentralization, and most of the security guarantees of the main Ethereum blockchain. Polygon is the most popular Layer-2 blockchain.

5.1.1 Implications

The goal of the study was to provide a description of the global NFT market ecosystem as it exists today. The main contribution of this thesis in this sense has been to perform an empirical analysis on a comprehensive database of the marketplaces operating in the NFT ecosystem, observing several aspects that have been already addressed in the scientific literature, but that lacked a study that evidenced it in an empirical way. In particular, the specific variables relating to the business models and to the technical specifications made by marketplaces have provided relevant information.

The study has found some implications that may result useful for different actors.

To the NFT artists, the research gives an overview of the current state of the various NFT marketplaces. The result of the study provides the advantages and disadvantages of every type of marketplace and can help in the decision of the platform in which to publish and sell their digital work. This choice is influenced mainly by the intentions of the artist and by the content that the creator wants to publish, but also by other factors such as the blockchain networks that he wants to support and the fees that he is willing to pay to mint the NFT and to give the platform, and that he expects to receive as a form of royalty.

Moreover, the results illustrated can be useful for NFT entrepreneurs who are developing or want to develop an NFT marketplace. They will find interesting the

insights regarding the business choices that the various platforms are making regarding the platform fees and the royalty fees, since these are changing radically in the last few months. Subsequently, the analysis of the technical specifications can help them in the choice of the most suitable blockchain network, standard protocol and supplementary platforms for their marketplace. All of these will help them to design a business aligned with the direction of the development of these technologies.

Finally, the NFT enthusiasts and passionate about NFT may be interested in this paper, to help them choose the best platform in which to search, buy and eventually display the NFT. Since this may be an important investment, it is better to have a complete overview of the market and understand its current scenario to make assumptions about their future development or applications.

5.1.2 Limitations and future research

The analysis of this thesis presents some limitation which may represent concrete opportunities for future research.

The empirical research has been brought with a descriptive method, that aim to highlight the current state of development of the marketplaces based on non-fungible tokens. However, there are connections of cause-effect between the different variables, and it cannot be concluded that some choices have led to greater volume sales, since this is still a new technology which is still in the early phases of its hype cycle.

In addition, the choice to exclude NFT marketplaces that belong to cryptocurrency exchange platforms has been taken because of the limited instruments that the analytics websites provide. Indeed, the literature, the official websites of the platform and instruments like Dune.com did not allow me to gather specific data regarding volume sales of the NFT marketplaces of the exchange exclusively. Indeed, only volume sales of the whole exchange were provided. However, these have a major role in the market, and it would be interesting to include them in order to compare them with the other NFT marketplaces.

Moreover, some individual areas may be interesting to be thorough. For example, the fashion industry is investing so many resources in this ecosystem, and the major firms and brands are providing their proprietary NFT collections.

Regarding the technical variables, it should be noted that the distribution of the proprietary tokens of the marketplaces lacks a classification of the functionality of them. Since the tokens may be used for different purpose and can be distinguished in utility tokens and governance token, it would be interesting to see how many marketplaces use each category.

Another phenomenon that exploded recently in the NFT marketplace are the aggregators. Indeed, platforms like sudoswap and Blur are radically changing the market and are forcing the biggest players like Opensea to review their policies and strategies in order to not lose the lead. So, trends like setting to zero the fees given to the platform and making the royalty fees for the creators optional are spreading all over the marketplaces.

Eventually, the findings of this study raise new, possibly intriguing research questions given the novelty of the technology under review. Will the spread of the NFTs lead to the development of a dominant design? How and when will this technology reach the mass adoption? Is the metaverse going to be important for this?

5.2 Conclusion

Non-fungible tokens are a technology that gained popularity in recent years as a new way for creators to monetize their digital content and for collectors to acquire unique pieces of art. They can represent various digital items, such as art, music, videos and other forms of creative content. They are designed to give ownership and authenticity to digital consent, making it possible for creators to sell their work as unique, one-of-a-kind items, just like physical art or collectibles.

The applications are evolving, and these are spreading in many sectors, from art to gaming. Many marketplaces are raising during the years and each of them have its own peculiarities that make their platform unique. The growing interest in these technologies by companies has led many researchers around the world to study the topic and has also inspired the objective of this research: to describe the current ecosystem of these marketplaces whose business model is based on the use of NFTs to investigate future directions of development and innovation of these technologies.

In order to reach this objective, an empirical research has been made on NFT marketplaces of the world, as well on the design, business and technical elements they have chosen to implement.

The process of gathering and classifying data to develop the database of analysis has been made in cooperation with the Blockchain and Distributed Ledger Observatory of Politecnico di Milano. They provided a raw sample of NFT marketplaces, sources and instruments, a structure for data categorization and support for the research. The data collection phase led to a census of 100 NFT marketplaces, which has seen a volume sale of $51 billions USD, excluding the activities suspected to be considered as "wash trading".

The overview of the market evidences the dominance of a few marketplaces in the ecosystem at the moment: OpenSea has always been the most popular marketplace, Axie is the most popular game, CryptoPunks are the most profitable collection and Magic Eden is the biggest marketplace on Solana blockchain. However, a new entrant called Blur, which was born as an aggregator and become now a marketplace has

revolutionized the market. Indeed, NFT aggregators are acquiring popularity thanks to the smooth user experience and vast variety of NFT they provide.

By now the hype of this technology that characterized the previous year has vanished, the crypto winter has bankrupted many platforms, and only the more convincing players have survived. An important factor is the location of the marketplace. Since this is a new technology, the countries have not applied a regulation for them, so taxes and restrictions may vary. United States host most of the platforms.

Regarding the business model, many marketplaces are setting the platform fees to zero in order to incentivize users. On the other side, the royalty fees are more and more set as optional, taking away from the creators one of the biggest advantages brought by the non-fungible tokens. Marketplaces tend to offer the most purchase methods and give their customers the chance to mint NFT and purchase them directly with credit cards. Regarding the governance, centralized marketplaces are dominating the market thanks to their better user experience, but the need for decentralized platform through governance token and on-chain data is clear. These kinds of marketplaces are aiming to close the gap by perfecting the user interface, which will be a major factor for the users in the future.

The technical analysis has evidenced that Ethereum is still the blockchain network that is supported the most despite its limits evidenced by its competitor, which in parts are exceeded thanks to the proof-of-Stake. The most important marketplaces support various networks and layer-2 blockchains are a new phenomenon that is becoming popular. Many blockchains are introducing new standards, but the majority are compatible with the Ethereum standards ERC-721 and ERC-1155. Moreover, NFTs that represent digital art generally do not store the associated file on the blockchain due to the large size of such a file, making it vulnerable to a link rot.

There are many limits in the user experience of the platforms, which will be crucial to be surpassed in order to reach the mass adoption of NFTs. For example, the marketplace's mobile applications do not allow to buy any NFT, but only to browse them. Furthermore, users have to make a wallet in order to purchase any digital work, which make the

entrance in this ecosystem harder. Regulations and taxes are still in development but will influence the spread of the technology a lot, and rights like copyright must be discussed. Finally, it will be interesting to see the impact of the entrance of new NFT marketplaces of big technology companies like Amazon, which is launching its platform in April, and the Metaverse will have an important role in the diffusion of these technologies.

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