Exploring Use Cases and Evaluating Tools for Web3 Technology

A Major Qualifying Report
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements
For the Degree of Bachelor of Science in

COMPUTER SCIENCE

By:
Eric Zhou
Jacob Byrnes
Kody Robinson
Jack Lynch
Michael Gatti

Advised by:
Craig Wills

Date:
March 2024

Table of Contents

Abstract

This report provides a comprehensive exploration of Web3 technology use cases across diverse sectors, including gaming, real estate, and supply chain management. Through in-depth analysis, we delve into the potential and challenges of Web3 implementation. We examine its unique capabilities such as peer-to-peer transactions, versatile token creation, and smart contracts. Additionally, we highlight the evolving landscape of Web3 development, addressing both opportunities and obstacles faced in creating decentralized applications (dApps). By combining our preliminary research with practical development, this report offers valuable perspectives for stakeholders looking to leverage Web3 solutions, concluding with recommendations to navigate this dynamic and promising technology effectively.

1. Introduction

Web3 technology represents the next frontier in the evolution of the Internet, emphasizing decentralization, enhanced user privacy, and the integration of blockchain technology. This report delves into the multifaceted impact of Web3 across various sectors, including gaming, real estate, and supply chain management, aiming to uncover the transformative potential and practical challenges of adopting Web3 technologies.

1.1 Motivation

The motivation behind this study stems from the proliferation of Web3 in media and the consequent need for a nuanced understanding of its implications across different industries. By exploring a diverse range of use cases, this report aims to provide a comprehensive evaluation of Web3 tools, highlighting the benefits and identifying the hurdles encountered during implementation.

1.2 Objectives

Our objectives are twofold: firstly, to explore the application of Web3 technology within selected sectors and evaluate the effectiveness of existing tools; and secondly, to derive actionable insights and recommendations based on these evaluations. Through this approach, the report endeavors to contribute to the broader discourse on Web3 technology, offering a grounded perspective on its current utility and future prospects.

1.3 Report Organization

The report is organized as follows:

Section 2 provides background information on Web3 technology and the principles of blockchain. It additionally describes Smart Contracts and NFTs, offering an overview of key Web3 technologies, and ends with already existing industry applications.

Section 3 provides a synopsis of the development tools used during our research. It describes the ecosystem of Web3 development tools and gives insight into the interplay of components.

Section 4 overviews the benefits of Web3 and describes our approach for selecting use cases that exemplified these benefits. It describes the thinking behind choosing each of our three use cases and how they fit into the broader Web3 landscape.

Sections 5, 6, & 7 go through the design & implementation of the applications for our selected use cases. Each chapter delves into the development tools used for a singular application: Web3 Game Development, Real Estate Transaction Management, and Supply Chain Management, respectively, while also describing their purpose and functionality. The three sections conclude with feedback from users and commentary about the application development process.

Section 8 is a discussion on the commonalities across the applications.
It also addresses the limitations of the study and warns about the hurdles that Web3 developers may encounter.

Section 9 synthesizes our findings, drawing conclusions from our analyses, and offers a forward-looking perspective on the future work.

2. Background

Web3 represents the next evolution of the Internet, emphasizing decentralization and enhanced user privacy. At its core, Web3 leverages blockchain technology to create a more secure, transparent, and user-centric web, where users have control over their own data, identity, and transactions.

One key component of this new web paradigm is the support of decentralized applications (dApps) that run on peer-to-peer networks, rather than centralized servers, offering increased resistance to censorship and downtime. Tokenization, through non-fungible tokens (NFTs) and cryptocurrencies, facilitates digital ownership and value exchange, enabling new economic models and opportunities for creators and users alike. Web3 also aims to make the Internet more intelligent and personalized, enhancing search capabilities and user interactions. Through these advancements, Web3 promises to transform how we interact with the digital world, emphasizing autonomy, user empowerment, and a more equitable distribution of the Internet's value.

2.1 Web3 Evolution

Web3 differs significantly from its predecessors, Web 1.0 and Web 2.0, in several key aspects. Web 1.0, often referred to as the "static web," was characterized by static web pages with limited interactivity and primarily served as an information repository (Hendler, 2009). Users were passive consumers of content, with limited opportunities for participation or collaboration.

In contrast, Web 2.0, which emerged around the mid-2000s, introduced dynamic and interactive web experiences fueled by user-generated content, social media, and collaborative platforms. (Hendler, 2009) Web 2.0 facilitated the rise of social networking, blogging, and content-sharing platforms, empowering users to create, share, and interact with content.

Web3, on the other hand, represents a paradigm shift towards a more decentralized web. Unlike Web 2.0, which focused on enhancing user experiences through social interaction and collaboration, Web3 emphasizes machine-to-machine communication, data interoperability, and semantic understanding of content. It leverages technologies such as artificial intelligence, blockchain, and the Semantic Web to enable more personalized, contextually relevant, and secure online experiences.

Furthermore, Web3 embodies principles of decentralization and data sovereignty, aiming to empower individuals with greater control over their data and digital identities. Unlike Web 2.0 platforms, which often centralize user data and monetize user interactions, Web3 platforms prioritize privacy, security, and user autonomy. Decentralized technologies like blockchains enable peer-to-peer transactions and secure data storage, reducing reliance on intermediaries and enhancing trust in online interactions.

Figures 2.1, 2.2, and 2.3 below represent a timeline of the World Wide Web, quickly summarizing the main features of each iteration and highlighting the changes as it progressed.

Timeline of World-Wide-Web:

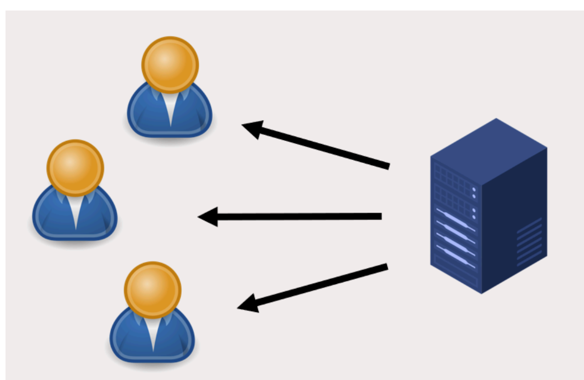


Figure 2.1: Web 1.0 (one-way communication)

Web 1.0 (Late 1980s to early 2000s): Introduced static HTML pages and limited interactivity, mainly offering one-way communication with centralized control of content creation.

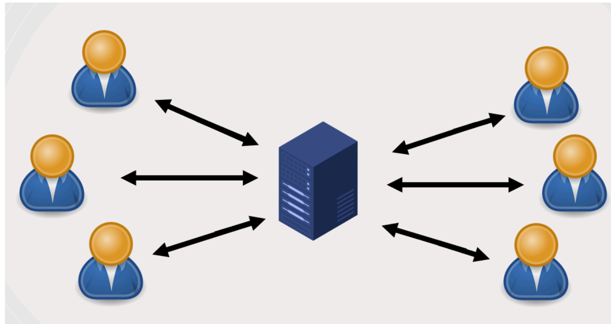


Figure 2.2: Web 2.0 (user-generated content)

Web 2.0 (Early 2000s onwards): Transitioned to dynamic and interactive content, emphasizing user-generated content, social media platforms, and a richer user experience with collaborative and community-driven elements.

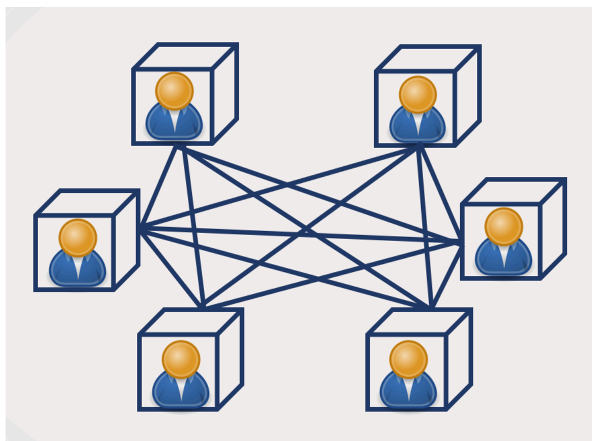


Figure 2.3: Web3 (decentralized web)

Web3 (Ongoing development): Aims for a more intelligent, decentralized web, with features like semantic understanding, personalized experiences, increased interoperability, and integration of artificial intelligence technologies. Blockchain is often used to enhance security and privacy.

This new stage of the interconnected web represents the next part of the Internet's evolution, incorporating decentralization, blockchain technology, and token-based economics. It signifies a major shift from centralized data control to a decentralized model, empowering users with greater control and ownership of their data and digital assets.

2.2 Blockchain Technology

Blockchain technology, essentially a distributed digital ledger system, has emerged as a potential revolutionary force in various industries owing to its decentralized nature. The underlying framework used to achieve a decentralized network free of any centralized authority is the use of a peer-to-peer network, where a group of computers possess equal authorization and capabilities (Zheng, Xie, Dai, Chen, & Wang, 2017). This decentralized structure offers unique key advantages as compared to a centralized solution:

Transparency

Blockchain provides a high level of transparency by offering a shared, immutable ledger visible to all nodes in the peer-to-peer network. Every transaction or data entry is recorded publicly throughout the network, minimizing the risk of fraud and ensuring a clear audit trail.

Redundancy

Since data is not stored in any central authority, it is distributed across the entire network. Full nodes store the entirety of a blockchain ledger, while light nodes store enough necessary data to verify transactions and can prune unneeded transaction history after validation. Several copies of the complete ledger exist across the network, and in turn provide enhanced data integrity and resilience in the event of failure on one part of a network.

Efficiency

Traditional centralized systems often encounter bottlenecks and extremely large single points of failure. In contrast, blockchain's distributed nature enables more efficient parallel processing and eliminates the need for intermediaries.

Security

Blockchain security represents a fundamental shift from traditional security measures due to its inherent design principles (Zhang, 2019). Unlike centralized systems where security focuses on protecting a single point of failure, blockchain employs a decentralized architecture, distributing its data across multiple nodes. This distribution ensures that no single entity has control over the entire network, significantly reducing the risk of data tampering, fraud, or centralized attacks. Each transaction on a blockchain is encrypted and linked to the previous transaction, creating an immutable ledger. Once data is recorded, it cannot be altered without altering all subsequent blocks and gaining consensus from the network, which is computationally impractical. Additionally, blockchain uses cryptographic algorithms to secure data transfer and access, providing a layer of security fundamentally different from traditional systems that often rely on perimeter security and centralized trust models. This makes blockchain uniquely resistant to data breaches, making it a robust solution for applications requiring high levels of trust and security.

Ethereum Network

When discussing blockchain technology, it is essential to highlight Ethereum as one of the premier blockchain platforms currently available. Founded by Vitalik Buterin (Kim, 2020), Ethereum first launched in 2015 and quickly emerged as a frontrunner due to robust capabilities and initial support for smart contracts to create dApps. Ethereum's main network, referred to as the "mainnet", is where actual transactions with monetary value occur. Ethereum also offers test networks, commonly referred to as "testnets", which provide the necessary tools and resources to develop and test dApps without incurring real-world costs. Examples of Ethereum testnets are mentioned later in Section 3.

2.3 Non-Fungible Tokens (NFT)

Non-fungible tokens (NFTs) are digital assets that represent ownership or proof of authenticity of a unique item or piece of content, utilizing blockchain technology (Wang, 2021). Unlike cryptocurrencies such as Bitcoin or Ethereum, which are fungible and can be exchanged on a one-to-one basis, NFTs are unique and cannot be exchanged on an equal basis, hence the term “non-fungible”. NFTs can represent a wide array of digitally native assets, including but not limited to digital art, music, videos, and in-game items. Each NFT contains metadata that provides a digital signature to certify its originality and ownership, which is recorded and verifiable on the blockchain. This technology provides a mechanism for authentic digital ownership and resale rights.

2.4 Smart Contracts

Another fundamental technology that enhances the utility of blockchains are smart contracts. Blockchains such as Ethereum were developed with the eventual goal of establishing a secure peer-to-peer network for running smart contracts and decentralized applications, going beyond the normal purpose of being a digital currency like Bitcoin.

The term 'smart contract' is thought to have been first defined by computer scientist Nick Szabo in a 1994 article. It refers to nothing more than a computer program written to represent a self-executing agreement between involved parties (Szabo, 1996). These automated programs are stored, replicated, and run on nodes in a blockchain as a calculation of the network.

With this comes various benefits which are listed below (IBM, 2024):

- **Transparency:** Terms are accessible to all involved parties as records are public on blockchains,
- **Security:** In addition to transaction histories being public, smart contracts typically operate with high levels of data encryption ,
- **Efficiency:** Smart contracts can save time as the software instantaneously executes once conditions are met; eliminating the need for manual processing of documents,
- **Redundancy:** Since blockchain records are spread throughout the network, data can be easily recovered in the event of the loss of a node
- **Going Green:** Smart contracts can reduce the need for traditional paper documents, potentially contributing to environmental sustainability.

However, there are also limitations (Barley, 2024):

- **Difficult to Change:** Once a smart contract is deployed to an address somewhere in the blockchain, it remains there for as long as the blockchain exists. Due to their immutable nature, any future updates and additions to a smart contract will not be reflected on the currently deployed version. The only method to migrate to an updated smart contract is to redeploy it at a new address and facilitate migration for all users.
- **Human Factor:** Smart contracts are created by developers, and are subject to their implementation and understanding of the contract terms. Developers must ensure that loopholes and major bugs are addressed before deploying a smart contract, as once deployed, it remains on the blockchain until either the SELFDESTRUCT opcode is called on the contract (EVM Codes, n.d.), or the blockchain ceases to exist.
- **Limited Regulations:** Currently, the United States lacks a unified regulatory body for overseeing blockchain technology. Instead, several agencies are involved that do not appear to have found common ground, including the U.S. Securities and Exchange Commission (SEC), Commodity Futures Trading Commission (CFTC), and the Financial Crimes Enforcement Network (Georgiades, 2023). An example of these differing views lies in a 2022 charge against a Coinbase product manager that was brought forth by the Department of Justice and SEC, whose approach was heavily criticized by CFTC's commissioner Caroline Pham (Dewey, 2024). Furthermore, an article published by the National Conference of State Legislatures (NCSL) shows that few states enacted legislation specifically regarding blockchain technology, with many still in the research phase regarding its applications (Morton, 2022). Similarly, a Wharton article also published in 2022 highlights the general lack of uniformity across state-level cryptocurrency regulation, as there is no federal framework in the United States (Jasperse, 2022).

Several languages can be used to create smart contracts, with the most popular one (as well as the one being used throughout this project) being Solidity. Widely adopted for Ethereum-based contracts, Solidity is a high-level language created for the purpose of smart contract development. It is similar in syntax to JavaScript and is based on popular language structures such as C/C++ and Python, making it easily accessible to a broad range of developers.

Once the smart contract has been written, it must be converted from high-level code into machine-readable bytecode. This can be done with any viable Solidity compiler, and notable tools are mentioned later in Section 3.

Once a contract gets compiled, the bytecode is then stored on the blockchain with an address assigned to it. This address is determined by the address of the account creating the contract (message sender) and the number of transactions they have sent (nonce), which are hashed with the keccak-256 algorithm. To interact with the smart contract, developers can also create Application Binary Interfaces (ABIs), which similar to Application Programming Interfaces (APIs), which is an interface defining the set of rules for interacting with smart contracts from an application, and are typically formatted as a JSON document.

Deploying smart contracts however is not a cost-free process. It typically requires a certain amount of cryptocurrency to compensate network nodes for the computational resources consumed. On the Ethereum blockchain, this fee is referred to as gas, and is typically measured in units of GWEI, equivalent to a billionth of one ETH (Conversion rate is valued at $2,878.47 USD as of February 18th, 2024). Gas prices on the Ethereum network are dynamic, fluctuating based on the level of demand for computational resources, and being influenced by factors such as network congestion and complexity of operations being performed (Garnett, 2024).

Additionally, subsequent transactions made between the smart contract also have to incur fees, which is calculated as the product of the gas price as mentioned above, along with the total amount of gas used in the transaction (Frankenfield, 2022). Two upper bounds for the amount of gas spent are typically put in place; one is the amount of gas set by the user that they are willing to use for the transaction, and another set by the network which represents the maximum amount of gas allowed in a block, which are batches of transactions with a hash of the previous block in the chain. Development environments often provide mechanisms for auto-generating optimal gas prices based on current network conditions. Higher gas costs can incentivize miners (computational work done across network nodes to validate information contained in a block) to prioritize transactions.

2.5 Example Industry Applications

Having established a fundamental base of knowledge of blockchains and smart contracts, we now examine and highlight tangible examples of industry applications that demonstrate the transformative potential across sectors.

2.5.1 Healthcare

In the realm of healthcare, blockchain technology has shown potential to revolutionize the way medical data is owned, managed, and utilized. One of the biggest impacts would be a shift towards a patient-centric model, where patients will have more control over their health data. One example company that has been experimenting with this model is DeHealth, an international brand headquartered in the United Kingdom. They have developed a blockchain-based web app called DeHealth App, which can allow users to securely and autonomously store medical data on their DHLT network, which is a decentralized storage for health data (DeHealth, 2024). Most importantly, users have the ability to sell and monetize their anonymized data using the DHLT token, allowing users to be rewarded when contributing to medical studies. Figures 2.4 and 2.5 show samples of the DeHealth App UI.

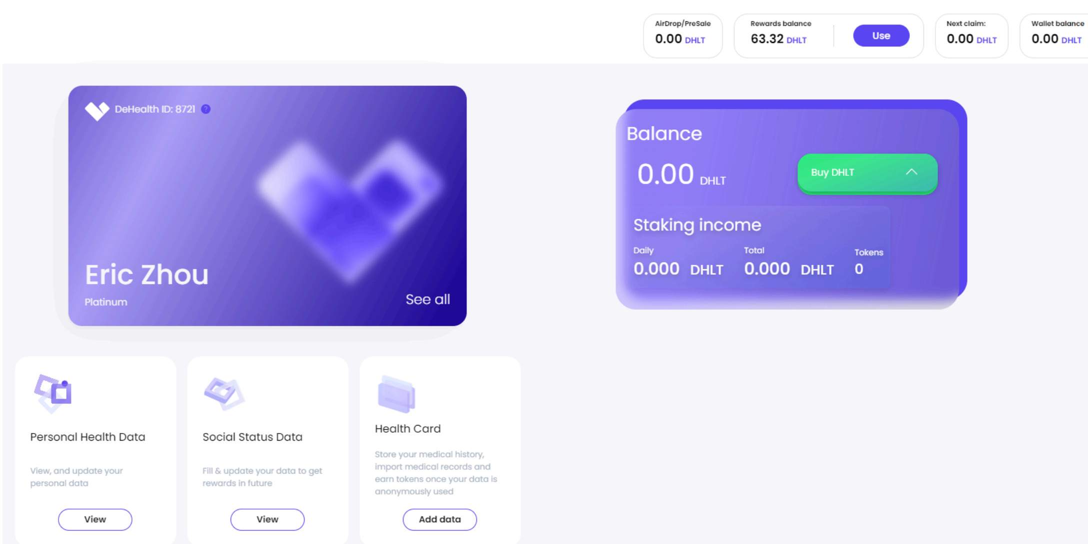


Figure 2.4: Example homepage of a user's account on the DeHealth App.

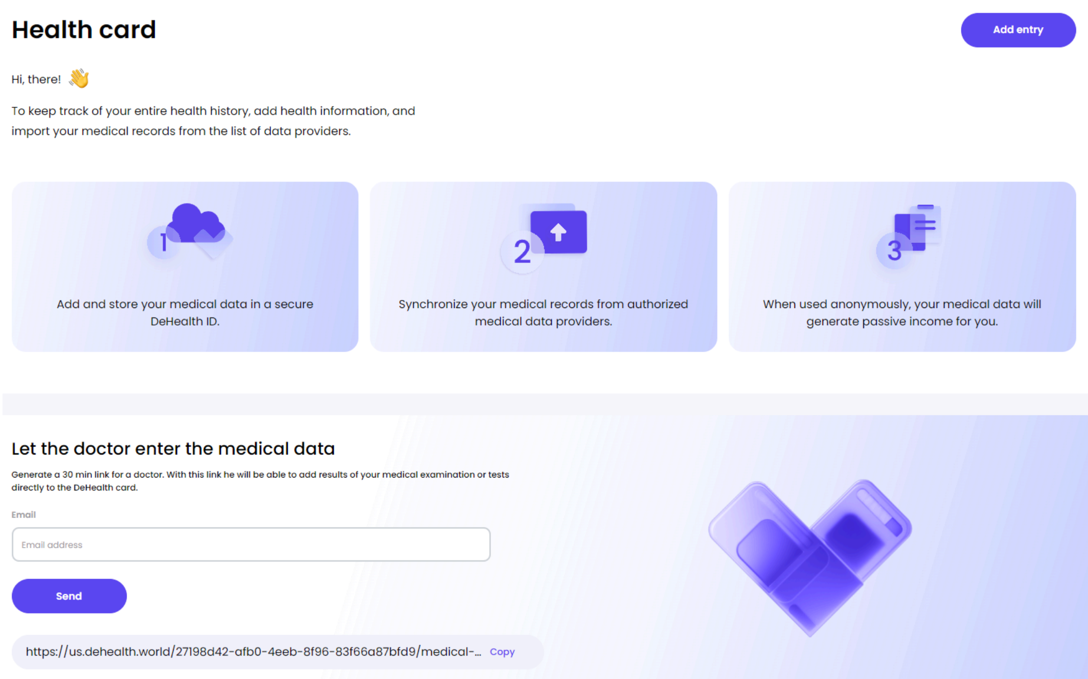


Figure 2.5: How medical data can be uploaded on the DeHealth App.

Another company that aims to grant more control to the patients is Nebula Genomics, which offers whole genome sequencing at affordable prices. Additionally, they provide services such as weekly DNA reports, ancestry analysis, as well as health risk assessments. The cost of genome sequencing has significantly dropped from the first complete human genome sequence that racked up a total of $3 billion USD. Figure 2.6 contains data from the National Human Genome Research Institute (NHGRI) between 2001 to 2022, and showcases an almost exponential decrease in sequencing costs.

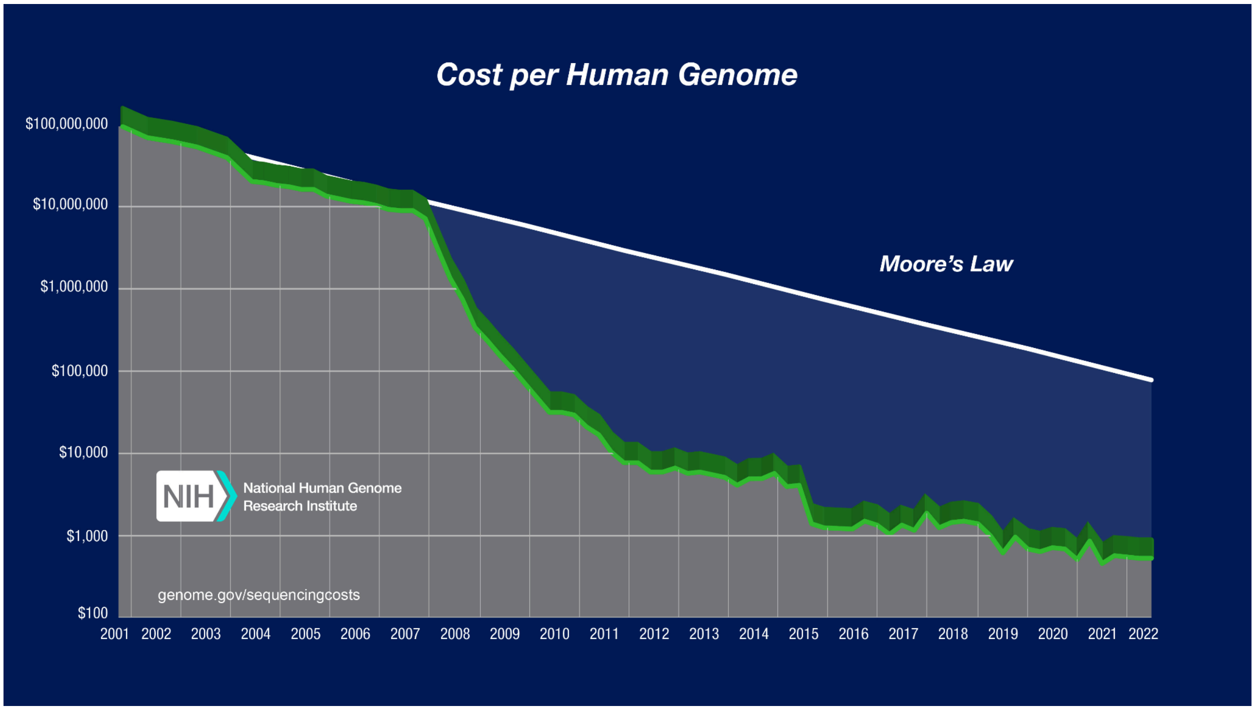


Figure 2.6: Human Genome sequence cost. Graph via NHGRI (2023).

Nebula Genomics further drops the price down to around $299 for a basic DNA kit and a lifetime membership to be able to maintain access to test results. The company utilizes blockchain technology to build a multiparty access control system, giving users full control over their genomic data, as well as help reduce the risk of security breaches and prevent data privacy infringements (Nebula, 2024). Co-Founder George Church, who is also a professor at Harvard Medical School, has conducted studies into the usage of blockchain technology as a means of reinforcing genomic data generation and access (Grishin, 2018). Another study performed in 2019 proposes a secure citizen-centered platform where users can share genomic and clinical data in an encrypted form, while attempting to maintain the data-owner-controlled and auditable qualities that make blockchain technology so appealing (Grishin, 2019).

2.5.2 Elections

Elections are a crucial democratic aspect that empower the people to choose representatives who best advocate their beliefs and values. Consequently, election integrity becomes a paramount issue, as it helps guarantee the fairness of procedures and allows for a better democracy.. With the secure nature of blockchain technology, it would make sense to apply this technology to our voting systems. With Web3's heavy emphasis on validation, these systems make voter authentication more streamlined while also ensuring that voters do not vote twice or attempt to vote under someone else's name. Web3 election applications are still in their infancy, but already demonstrate promising solutions. For instance, many of these systems include an audit feature which automatically checks to make sure everything is secure and nothing has been altered. These systems allow for the user to track and see that their vote was cast and counted. They also allow the user to alter their vote before the election ends as a safeguard against hackers who may attempt to alter their vote (Benabdallah et al., 2022).

Due to the concerns around blockchain as well as online voting as a whole, there have not been any significant elections that have utilized Web3 technologies. However, that does not mean that there are no companies that are attempting to make blockchain voting more prominent. The company that seems to be leading this is named Follow My Vote, which aims to make an open source voting software which can be utilized to vote as well as track a user's vote and even change it if desired. This information, as well as access to their github which contains their open source software, is available on their website (Follow My Vote, n.d.).

2.6 Summary

Web3 marks a significant shift in the Internet's evolution, transitioning towards a decentralized, user-centric platform that prioritizes security, privacy, and user control over personal data. Leveraging blockchain technology, Web3 enables the creation of dApps that operate on peer-to-peer networks. It introduces tokenization through non-fungible tokens (NFTs) and cryptocurrencies, paving the way for digital ownership.
Unlike its predecessors, Web 1.0's static web pages and Web 2.0's dynamic, social media-driven platforms, Web3 emphasizes semantic web capabilities, data interoperability, and machine-to-machine communication. It stands out by enabling data sovereignty, reducing reliance on centralized intermediaries through blockchain's transparent, secure, and efficient data management. Ethereum, a leading blockchain platform, supports the development of smart contracts and dApps, further enhancing Web3's utility. However, challenges such as immutability, potential human error in smart contract creation, and

regulatory uncertainties remain. Solidity, the language for Ethereum smart contracts, alongside computational fees or "gas," facilitates these contracts' deployment and transactions, encapsulating Web3's essence as a phase focused on decentralization, user empowerment, and a more equitable internet value distribution.

3. Project Development Tools

Throughout the exploratory phase of this project, we encountered numerous Web3-related tools and software, as well as tools not strictly related to Web3 but still would become crucial components of our final applications. A majority of them serve as the building block for the development and deployment of dApps onto blockchains.

At the heart of the ecosystem lies the Ethereum blockchain, which in Web3 acts as a backend solution that revolutionizes the way data is stored and validated as mentioned earlier in Section 2.2. Ethereum also ends up being the standard blockchain to develop dApps in thanks to it being the first smart contract blockchain, as well as retaining its longevity and popularity since its launch back in 2015. Because of this decentralized manner, the "backend" of dApps rely less on traditional backend servers and more so on smart contracts.

Similar to a backend service, it has functions/endpoints, and once deployed lives permanently unalterable on a blockchain, making for a transparent backend component that utilizes the idea of decentralization. The frontend of a dApp is typically just a website that has functionality to communicate with the specified smart contract on the blockchain, and is typically developed in JavaScript with libraries such as React for building the user-interface, as well as libraries like Web3.js or ethers.js that provide interfaces for interacting with those smart contracts.

The two main components that the frontend requires to properly communicate with the smart contract is 1.) the address of the smart contract on the blockchain, and 2.) the compiled ABI of the smart contract that defines the functionality. Since transactions on the blockchain also require gas fees as mentioned in Section 2.4, a cryptocurrency wallet also needs to be included to properly communicate between the two ends.

Beyond the functionality that a smart contract can provide, there is an inevitable need to store files somewhere, and while blockchains technically have no trouble storing that type of data, most would rather use the InterPlanetary File System (IPFS). Both IPFS and blockchains share a commonality in that they run on decentralized networks, however serve different purposes. To understand why IPFS is the preferred method of storing data and files, it is crucial to understand that blockchains like Ethereum were never designed to store an extensive amount of files.

While it is possible to store any data desired on a blockchain, the exorbitant prices defer most from considering it as a feasible solution; according to Ethereum's yellow paper, there is a 20,000 gas fee to store a 256 bit word (Wood, 2024). As of February 18th, 2024, a quick estimate into an Ethereum gas price tracker puts the average gas price at around 30 GWEI (YCharts, n.d.), or 30th billionth of an Ether, which as of the same date is valued at $2,878.47. Doing the math, we can obtain a rough estimate of the cost of storing data on the Ethereum blockchain:

20,000 gas per 256 bits = 640,000 gas per Kb

Price per Kb = gasAmount * gasPrice
= 640,000 * (30 * (2,878.47/1,000,000,000)) = $55.27/Kb USD,

or the equivalent of $55,270,000/Gb, or about 19,000 ETH.

Which is where IPFS comes in; it can allow users to store and retrieve large quantities of data. This is possible because unlike a blockchain, IPFS does not require all data to be replicated by all nodes in a network, which allows it to scale to handle any amount of data (Tut, 2023). Once data gets uploaded, a unique cryptographic hash known as the Content Identifier (CID) is returned which represents the data. Providing the IPFS network with the hash returns the original data; any changes made to data also result in a change in the hash, ensuring integrity.

One key aspect to note is that unlike a blockchain, files on an IPFS network are not necessarily guaranteed to be permanently available. Nodes on an IPFS network can cache resources they get downloaded and keep them available for other nodes. However, storage is finite, and nodes will eventually clear out previously cached resources to make room for new resources in a process called garbage collection (IPFS, n.d.).

To help summarize the tools and pieces of software that we encountered throughout our exploratory phase, we developed an interactivity diagram to help illustrate the connections in the following Figure 3.1.

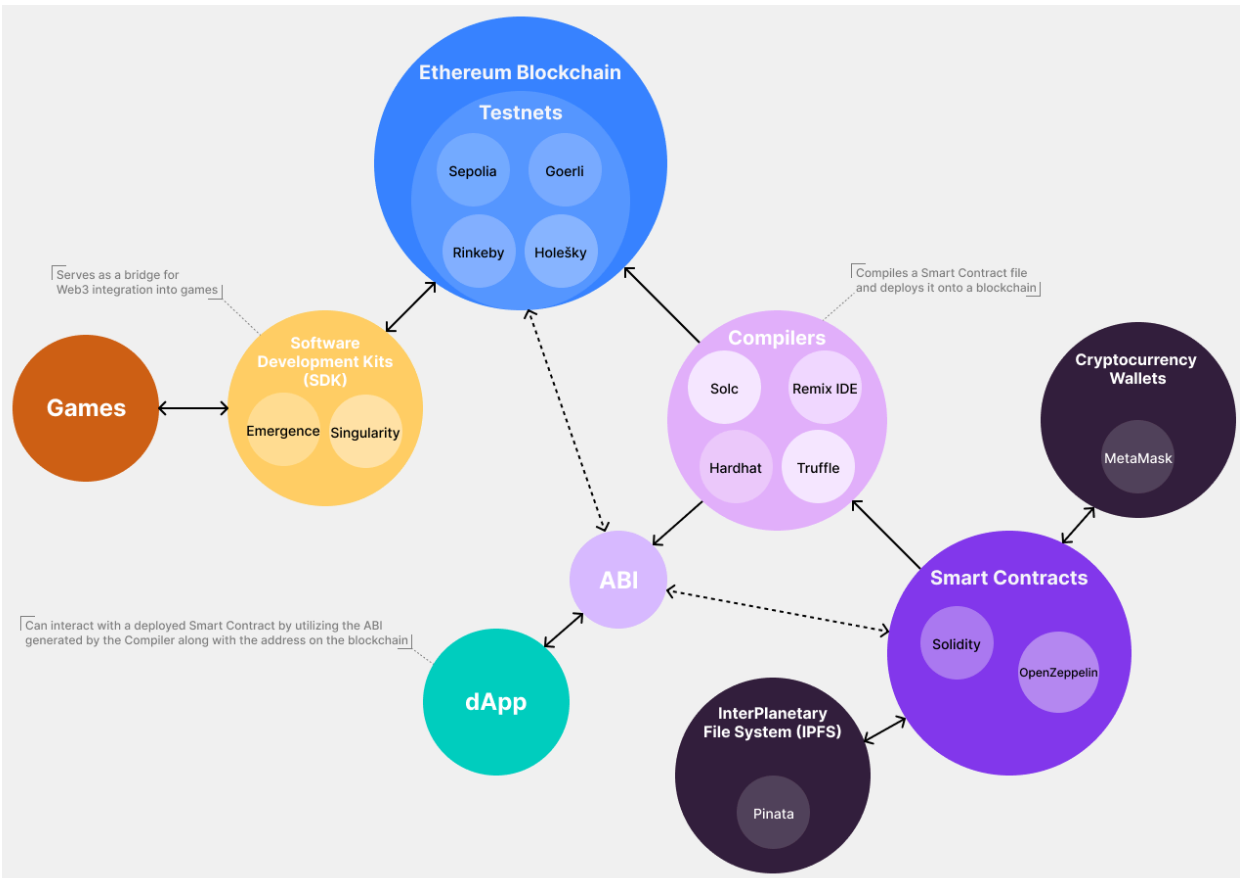


Figure 3.1 : Web3 tools interactivity diagram.

3.1 Ethereum Blockchain

As mentioned earlier in Section 2.2, Ethereum serves as the primary mainnet for this project. For the development and testing of our project, we opted to instead utilize the Ethereum's testnets for their cost-effective aspect while still being able to accurately replicate mainnet conditions. Figure 3.2 displays the life cycles of various deployed testnets.

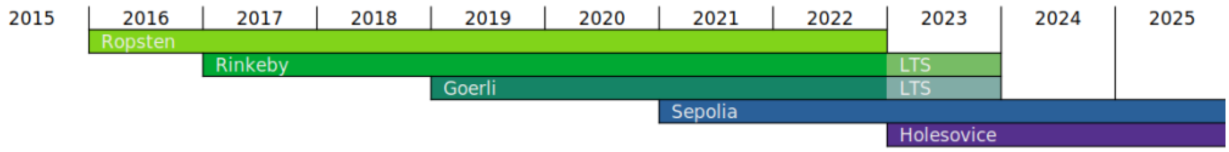


Figure 3.2: Ethereum testnet lifecycle. Image via GitHub (2022).

Notable testnets that we came across include:

- **Sepolia:** A proof-of-stake (PoS) testnet initially launched in 2021, and is currently the recommended default testnet for dApp development. Regarded as the most accurate representation of the Ethereum mainnet amongst the testnets.
- **Goerli:** Currently one of the most popular Ethereum testnets alongside Sepolia due to its stability and low transaction fees. However, due to more recent scalability issues and shortages of the Goerli ETH testnet token, it has been deprecated since the end of 2023, and will be sunsetted early 2024 (Moralis, 2023).
- **Rinkeby:** A proof-of-authority (PoA) test that was launched in 2017 and was also used to test dApps before being deployed to the Ethereum mainnet. Has been deprecated since October 2022 and was sunsetted in Summer 2023, making the testnet read-only for the foreseeable future (Werkheiser, 2022).
- **Holešky:** A newly introduced testnet that was intended to replace Goerli for testing validation, staking, and infrastructure development. As of now, Sepolia remains updated for dApp and smart contract testing.

3.2 Smart Contracts

Solidity has been established as the go-to programming language for smart contract development on the Ethereum Virtual Machine (EVM), and is also compatible across several other blockchains.

To assist with the creation of secure and efficient smart contracts, many libraries exist out there to help complement the development process. One of the libraries utilized in our project is OpenZeppelin, a library specifically designed for secure smart contract development, built on a foundation of community-vetted code.

Section 2.4 also mentioned how a smart contract first needs to be compiled before it can be deployed to a blockchain, and notable compilers include:

- **Solidity Compiler (solc):** The official compiler developed for the Solidity language.
- **Remix IDE:** Open source desktop application for developing, deploying, debugging, and testing Ethereum and EMV-compatible smart contracts. Remix Online IDE is a similarly powerful toolset that is browser-based and requires no setup.
- **HardHat:** Another Ethereum development environment for the facilitation of development and deployment of smart contracts.
- **Truffle:** Another comprehensive development framework with tools for smart contract development and deployment.

3.3 Cryptocurrency Wallets

In addition to a front-end component, a dApp also needs a cryptocurrency wallet to properly communicate with the blockchain. It is called a wallet because it operates similarly to a traditional wallet that stores cards. However, a cryptocurrency wallet stores passkeys required to sign and authorize cryptocurrency transactions (Frankenfield, 2023). One of the most popular crypto wallets is MetaMask, which is a software crypto wallet used to streamline access to dApps on the Ethereum blockchain as well as other supported blockchains. It can be installed as either a browser extension or on a mobile app, and provides an intuitive user interface for easy and secure access to one's cryptocurrency.

3.4 InterPlanetary File System (IPFS)

As mentioned in the beginning of this Section, files stored on the IPFS network are not necessarily guaranteed to exist indefinitely, as the IPFS network lacks the financial motives present in blockchains. One solution to ensure that data stays permanent on an IPFS network is to essentially pin the data to one or more nodes, and companies such as Pinata offer these pinning solutions for free under a small amount, and charge beyond (Koenig, 2023).

3.5 Web3 Software Development Kits (SDK)

To help bridge the gap between traditional applications and blockchain networks, various SDKs have been explored to help seamlessly integrate blockchain functionality, allowing for the creation of innovative solutions in various sectors. One of the primary sectors explored was gaming, and two primary SDKs were explored:

Emergence

An SDK for both Unreal Engine and Unity that offered an extensive collection of tools to help integrate Web3 into games (Emergence in Code Plugins - UE Marketplace, 2023; Emergence SDK | Infrastructure | Unity Asset Store, 2023). Key resources such as dynamic metadata that allows for a game to link in-game items to ones found in a crypto wallet made this SDK stand out in particular (Inventory Service, n.d.). Another great feature to this SDK was having a built in UI asset that provides a generated QR code to connect an outside crypto wallet (for example, one from Meta Mask). Once the setup, such as linking assets to the Sepolia testnet, was complete, the Emergence SDK proved to be a valuable tool for the game.

Singularity

An SDK for Unreal Engine that offers simple Web3 integration into the game engine (Singularity - Web3 Made Easy in Code Plugins - UE Marketplace, 2023). The SDK offers its own Singularity Wallet and has APIs and tools to enable Web3 and web2 integration into games. They have tools to enable the player to buy in-game tokens and purchase ERC-721 or ERC-1155 NFTs with fiat or crypto currencies (NFT Checkout, n.d). ERC-721 and 1155 tokens are two types of assets that are found on the Ethereum blockchain. The key difference is that 721 allows for non-fungible tokens while 1155 allows for both NFTs, fungible, and semi-fungible tokens (Davis, 2023).

3.6 Game Development Engines

Throughout the course of the research and development process, certain tools became of use to us that were not initially created to support Web3 technology. This was present through our development cycle for our game. We found assets that were designed purely for game development purposes and had previously mentioned SDKs and APIs that helped integrate changes we made with Web3 technology.

To save time from developing a game from scratch, our team tried out several game development engines and ultimately utilized one for the entirety of the game's development. Ward Jeff, a game developer and writer for ProQuest, defined a game engine as follows: "It exists to abstract details of doing common game-related tasks so that developers can focus on the details that make their game unique" (Ward, 2008). These tasks include; rendering models, loading features, and physics components such as gravity, etc. The utilization of game engines made the development process much more efficient. We tested two different engines before ultimately settling with one of them.

Unreal Engine 5

A game and media development engine that is offered by Epic Games. It contains tools to develop 2D and 3D games and is known for its proficiency in graphics rendering (Unreal Engine | The Most Powerful Real-Time 3D Creation Tool, n.d.). We originally planned to utilize this resource until it was discovered to have insufficient Web3 support.

Unity

A game development engine that is developed by Unity Technologies. It offers simple tools for creating games (Unity Real-Time Development Platform | 3D, 2D, VR & AR Engine, n.d.). We ended up choosing to use this engine based on its current 3rd party support for Web3 technology.

3.7 Summary

In conclusion, the exploratory phase of this project immersed us in a rich landscape of Web3-related tools and software, alongside vital components essential for our final applications. At the core of this ecosystem lies the Ethereum blockchain, serving as the backbone revolutionizing data storage and validation through smart contracts. These contracts, residing permanently on the blockchain, provide a decentralized backend for dApps, minimizing reliance on traditional servers.

Frontend development for dApps typically involves JavaScript frameworks like React, coupled with libraries such as Web3.js or ethers.js to interface with smart contracts. Additionally, integration of cryptocurrency wallets becomes imperative for seamless communication with the blockchain, especially considering gas fees.

For file storage, while blockchains are feasible, the InterPlanetary File System (IPFS) emerges as the preferred choice due to its scalability and cost-effectiveness. IPFS utilizes unique cryptographic hashes to ensure data integrity, although permanence is not guaranteed, as nodes may clear cached resources over time.

Transitioning from Web2 to Web3 entails leveraging a variety of tools and SDKs, particularly in gaming. SDKs like Emergence and Singularity facilitate Web3 integration into game development engines like Unity, enabling functionalities such as in-game token purchases and NFT transactions.

Moreover, non-Web3 specific tools like game development engines play a crucial role. Unreal Engine 5 and Unity were explored, with Unity ultimately chosen for its robust third-party support for Web3 technology.

This section’s journey through the Web3 landscape underscores the complexity and interconnectedness of its components, laying a solid foundation for the subsequent phases of our project. Through Figure 3.1, we have highlighted the tools encountered and their interactions within this dynamic ecosystem, providing a roadmap for the project's continued evolution.

4. Project Design

From the start of our research, Web3 appeared to offer a wide variety of benefits across various sectors, fundamentally changing how data is stored, how transactions are made, and how systems are secured. Here are some of the key benefits the technology promised to offer:

1. Decentralization: Blockchain operates on a decentralized network, eliminating the need for a central authority or intermediaries. This reduces the risk of centralized control and manipulation, making systems more democratic and resilient.

2. Transparency and Traceability: Every transaction on the blockchain is recorded on a ledger that is accessible to all participants, ensuring transparency. This feature is particularly beneficial in supply chain management, as it allows for the traceable history of products from origin to sale.

3. Immutability: Data recorded on the blockchain cannot be altered or deleted. This immutable record-keeping is crucial for financial transactions, legal contracts, and anywhere else where an unchangeable history is important.

4. Reduced Costs: By eliminating intermediaries and reducing transaction times, blockchain can significantly lower transaction costs. This is especially true in financial services, where blockchain can streamline processes and reduce fees associated with payments and remittances.

5. Data Integrity and Quality: Blockchain can enhance data integrity and quality by providing a single source of truth. This is particularly useful in scenarios involving multi-party processes, where consistent and accurate data is crucial.

Our goal for this project was to investigate potential use cases for blockchain technology and understand how to implement the benefits that were promised in our research. Blockchain was advertised as a way to disrupt a range of industries, including finance, healthcare, and supply chain operations. NFTs were promoted as a new way of ownership in our modern digital landscape, appearing poised to transform ownership within art, sports ticketing, and gaming.

We wanted to seek out use cases that exemplified these promised benefits and assess how well this technology lived up to its promises. To do this, we first looked at common themes and elements that gave Web3 applications their unique functionality.

The first of these was the usage of NFTs. More specifically, their use as a way to own digital assets. We found that while there was a lot of talk regarding the potential of NFTs, most of the projects we explored were focused on creating marketplaces to exchange these digital assets, whose value largely came from the ability to resell the asset at a higher price later. This led members of our team to explore ways in which NFTs could instead be utilized to improve user experience. The most apparent use case for this was Web3 based game development which was the first sector our team decided to delve into.

Secondly, with blockchain’s many promises to transform financial transactions, we decided to investigate use cases within this domain. We wanted to pick a use case that took advantage of decentralization and involved multi-party transactions. We also wanted to pick a case that if implemented in the market would reduce costs and benefit from ownership of digital assets. This made real estate a suitable choice. With the potential to streamline long term paper driven transactions and the potential to disrupt ownership through NFTS, we thought this would be an area ripe with potential.

Lastly, Web3 showed a lot of potential for situations where a need for complex management arises. Blockchain technology has shown promise of improving pipelines and increasing their efficiency. As a result, one sector that we ended up exploring was supply chain management, as modern-day supply chains commonly consist of a large network of users with different levels of authorization, potentially leading to numerous weak points in the system.

The next three sections delve into the design and implementation as well as the feedback and commentary for our projects in these three sectors.

5. Web3 Game Development

5.1 Design

Web3 games became a hot topic during the NFT bubble of the early 2020s, as both major and smaller independent studios attempted to introduce Web3 technologies into the gaming sphere. These attempts have been met with near universal backlash due to the monetary nature of NFTs and blockchain technology. While these games promised each player digital ownership of in-game assets, in reality it only served as a digital investment, with the purchasing of items in game with the purpose of selling them off later. It also did not help that the majority of these games did not utilize Web3 technologies as gameplay altering features, but rather used it as a way to sell in-game cosmetics and provide an extra source of revenue.

Examples of these games could be found everywhere during the height of the NFT craze in 2021, with indie developers and large game companies attempting to cash in on the hype. These games not only offered ownership of in-game assets, but also the potential to make money by selling them to other players who may want them. One popular example was Axie infinity, which was advertised heavily as a way to earn extra cash. The issues with these systems is they rely on new people buying into the system so that the established players can sell their assets, so when a video game's player count finally stagnates, so too does their in-game economy. That is exactly what happened to Axie Infinity, with the original game collapsing in 2022 (Bashir, 2022). However while the original game and website are unable to be accessed, the developers are still active and are still actively making Web3 games under the Axie infinity brand (The Lunacian, n.d).

With these issues in mind, we strived to create a simple video game that would showcase how Web3 can be used in a more gameplay altering way. Our goal was to give the user the promised digital ownership while improving the overall experience for the players through the use of Web3. While there are a few games that have had blockchain technology be used for gameplay purposes, these systems would often require the user to heavily invest into the system to obtain good items. For our design we wished to utilize Web3 technology to provide gameplay altering features while also keeping these features available to everyone.

We decided that our game would be a shooter, with the various guns that the player could wield being represented as NFTs on a blockchain. Our hope was that we could create numerous gun variants so that each player had a unique inventory of weapons that could be used. Of course, we also wished to keep the monetary cost to an absolute minimum to avoid creating a system which needs to be bought for access.

5.2 Implementation

Our original implementation was going to be a third-person shooter created in the Unreal Engine. Our first step was the development of a simple shooter game, which was relatively straightforward as there are plenty of already fleshed out samples and assets which our game could be built based upon. Next, we needed to find a Web3 SDK that we could use to implement blockchain features in the game. The first one that we found was called Singularity, which promised easy Web3 implementation and was touted as a free SDK. However, it was soon discovered that an access key was required to utilize the SDK. When emailing the developers to request an access key, they responded saying that they were selling the keys for $250 USD. Not wanting to endorse those kinds of business practices, it was decided that Singularity would not be the SDK of choice.

During this period, the project changed engines from Unreal Engine to Unity. This change was both to see if there were different Web3 integration options available, as well as Unity being a more familiar engine. One SDK discovered on Unity's asset store was Emergence, which offered similar features to Singularity while providing better documentation. This SDK was also truly free to download and use unlike Singularity. One of the main features of Emergence was their persona system, where a user could create a "persona", which would act as a character with a different appearance and description. These personas could then be selected and used in the game.

After re-making the third person shooter in Unity, another problem arose. The third person shooter we developed used the universal render pipeline (URP) to render the game, however, Emergence was not compatible with URP. As such, to use Unity's built in render pipeline rather than URP, the third person shooter idea was scrapped and instead development of a 2D platformer began, as this style of game was easier for us to make within Unity's built in render pipeline. This platformer was a simple one, with players having the ability to move and jump as well as shoot basic projectiles. The actual level would consist of a "lobby" area where the player would interact with the Web3 based inventory system, as well as a simple level with basic enemies for the player to defeat. The types of projectiles that would be shot by the player would be the focus of our Web3 implementation. For the purposes of the project, only two bullet patterns were made: a simple straight shot "pistol" and a spread shot "shotgun". The idea is to give the player ownership of one of these bullet patterns through the use of NFTs, then allow the player to equip and use that bullet type.

Emergence has a built-in prefab (a prefab being a complete instance of a game object), which already provides a basic inventory service as well as access to the persona system. The first implementation attempt involved utilizing the inventory system, which was supposed to display the user's NFTs. After making basic NFTs on the Sepolia testnet and adding them to our MetaMask wallets, one could access the Emergence inventory system to view their NFTs. However, the NFTs did not appear, and further attempts with NFTs on the Mumbai and Goerli testnets still did not yield any results. The documentation provided by Emergence did not help either, as none of the documentation relating to Unity mentioned the inventory system or any possible reasons why the NFTs would not appear on the interface. Another problem that appeared during this stage of development was the deprecation of the Goerli Testnet with much of the long term support for the testnet ending in early 2024. As a result, we defaulted to the Sepolia testnet as it was designated to be its successor. Moving on to finding other methods of creating an inventory system , the previously mentioned persona system became another way to implement the Web3 features. While these personas would not be used for their intended purpose of being individual characters, they would instead be used as a way to replace the inventory system by being used to represent the different bullet types.

With this new persona system in mind, work began on integrating Web3 into the game. Luckily, the Emergence prefab handled much of the work on the back end, however, there still remained a major issue with transferring the data from the personas to the game. There is documentation on the Emergence website about how to do this, all we were given was that the code required the user to be logged in to MetaMask to work. However, there was no event or variable that could be found in the documentation that would allow for the program to run the code only when the user is logged in. As a result, the code would be run when the program starts and would return a null value. After trying several different solutions, the problem was finally fixed after directly altering the code provided by the SDK to send the information about the persona to the player prefab. In our implementation, the persona system replaces the role of an NFT, with the name and description of the persona serving as metadata capable of informing the game about the corresponding weapon type.

With this change, the implementation was complete. When the user logs into the game, there is an in-game character in the lobby who explains how to access the Web3 features. The process starts with accessing the Emergence user interface, after following the instructions on the interface and logging in to MetaMask, the user would be prompted to select a persona. The user can then make a persona using their system, labeling it as either a pistol or a shotgun. Returning users could also select a persona that they had previously made. The game then checks the persona to see if it is a pistol (as shown in Figure 5.1) or a shotgun (as shown in Figure 5.2) and gives the player the respective bullet type.

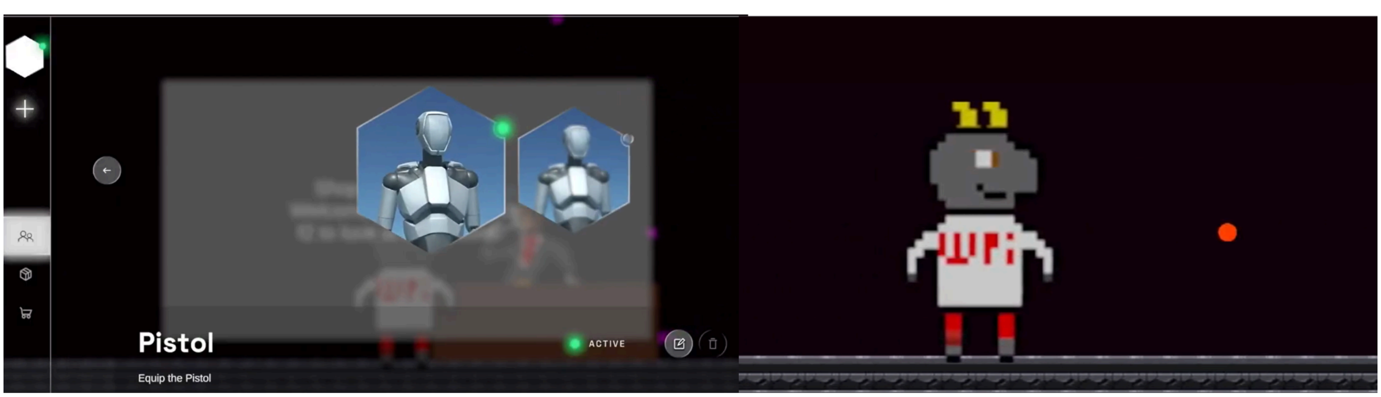


Figure 5.1: Screenshots of the game showing a player selecting the pistol persona and having the shotgun firing type because of it.

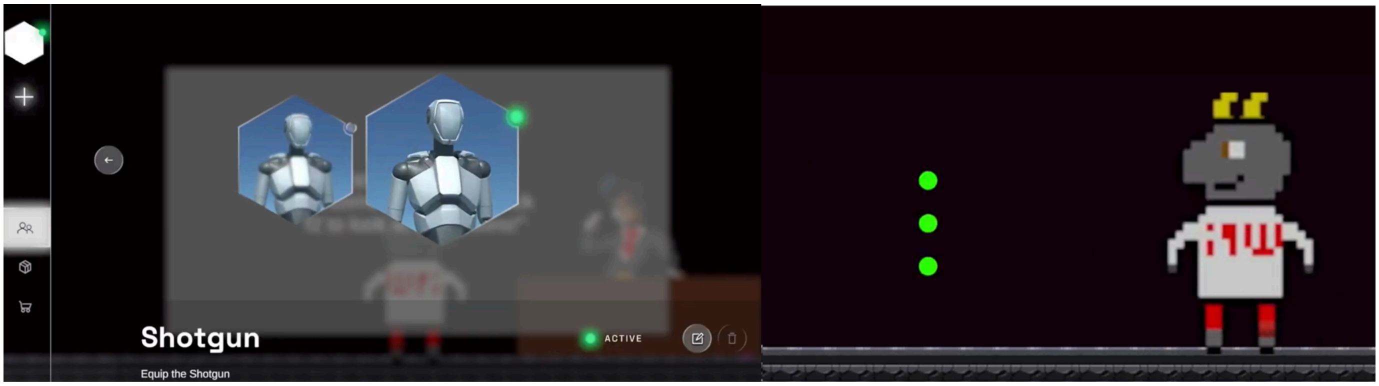


Figure 5.2: Screenshots of the game showing a player selecting the shotgun persona and having the shotgun firing type because of it.

If the persona's name does not correlate to a pistol or a shotgun, the player does not gain access to a gun. While this is unfortunate and does limit the player's creativity, this was done merely to keep the project as simple as possible, as this game is meant to be a proof of concept for Web3 technologies rather than a full-fledged game to be put on the market. In a proper implementation of this sample game, the name of the persona would not be tied to the type of bullets the player receives. Regardless, after obtaining their respective bullet type, the player could then enter the level, which is shown in Figure 5.3. After defeating all the enemies, they would be brought back to the lobby in which they could repeat the process. While a simple game, it does effectively show how Web3 can be used in a manner that does in fact alter gameplay as well as give the player ownership of their in game items.

Figure 5.3: A screenshot of the in-game level, the goal is to kill all the slime creatures such as the one on the left.

5.3 Feedback & Commentary

After completing the game, we had several people come and test it to determine how the inclusion of Web3 technologies affects the overall user experience. Our testers included people who would be considered fans of video games as well as people who have experience developing video games. Having both game designers and average people involved allows for a broader perspective, encompassing insights from both the producers and consumers of video game products.

The overall consensus on the Web3 aspects of our game was negative, with testers expressing their frustration with the implementation and how it takes away from the game. One major issue is that the user must log in to MetaMask to access personas, which is time consuming and takes the user out of the game experience. One tester noted, “More steps than necessary were added, and those steps were particularly inconvenient because they required you to use something outside of the game.” With video games already mastering the ability to select different weapons from an inventory, introducing an additional step solely for users to choose a weapon from the blockchain instead of an in-app inventory was generally regarded as an unwelcome change.

Along with this, after testing our game, Alex Bettios, a 7-year game developer and Computer Science student at the College of William and Mary mentioned: "On a surface level, the integration UI was clashing with the authored UI/UX of the game." Given that the Emergence SDK had a preset UI design, it somewhat limits how the rest of the game could look in terms of UI without completely overhauling the work previously done in the SDK. That left the team with two options: either change the UI to fit with Emergence which would force the game to have a certain aesthetic, or design our own implementation of Web3 and use more resources than would be reasonable.

The final roadblock is the preconceptions of cryptocurrency. As previously mentioned, the majority of Web3 games are primarily used as money-making schemes, a fact that is unavoidable in a lot of scenarios because the majority of transactions on the blockchain require monetary compensation. Another issue that affects people's perception of blockchain technology is its impact on the environment. One of our testers, a WPI Computer Science student and game developer named Cierra O'Grady mentioned that she is "concerned about the environmental impact." There is empirical evidence that supports her concerns. In a research thesis done by Harvard student Olga Martynov, they concluded that due to the specialized equipment and large energy consumption used to mine cryptocurrency (the paper specifically referenced Bitcoin), there has been and will be a substantial impact on the environment. Specifically, they mentioned that "under the current policy scenario, cryptocurrencies' annual carbon footprint by 2028 will account for approximately 1% of 2018 world's overall CO_2 emissions."(Martynov, 2020, p. 48) The calculations used in the thesis consider the current policies in place, indicating their susceptibility to change. However, an impact on that scale cannot be ignored when considering utilizing this technology.

From the results gathered, the consensus is that blockchain technology is overall considered to be not only an unwanted feature, but one that actively harms the final product when implemented in video games. Although there may be back-end value to utilizing blockchain in a video game, there is not enough benefit to the user to justify incorporating it. While Web3 technologies do certainly have a role in modern society, as of current, it does not appear to be a primary use case for this technology.

6. Real Estate Transaction Management

6.1 Design

The design of our real estate application focuses on leveraging Web3 technologies to streamline the real estate transaction process. The application intends to address several inefficiencies and challenges currently faced in the real estate industry, such as the time-consuming and paper-driven nature of transactions, and the high costs associated with title management and insurance. (Deloitte, n.d.) By utilizing blockchain technology and smart contracts, the application aims to explore ways to expedite pre-lease and deal due diligence. It also aims to reduce fraud and simplify the title records checking process as well as enable easier, transparent, and efficient management of properties. The decentralization aspect of Web3 is particularly beneficial here, allowing for a more transparent, secure, and efficient process that gives all parties involved a clear and immutable record of transactions.

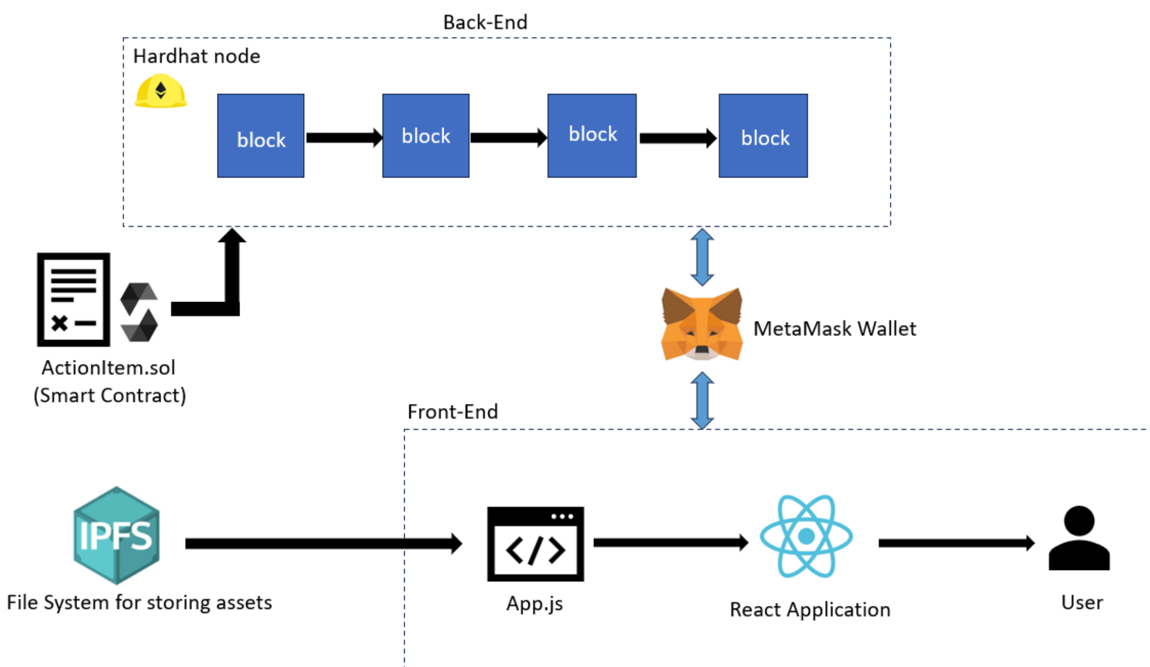


Figure 6.1 Architecture of Real Estate Transaction Management Application.

As shown in Fig. 6.1 above, the user interface was developed with React, an open-source JavaScript library. On the Web3 development front, several tools were instrumental in managing and securing the decentralized aspects of the application. IPFS (InterPlanetary File System) was utilized for storing metadata related to real estate transactions. As a peer-to-peer hypermedia protocol, IPFS enhances the application's speed, safety, and openness. This makes it a crucial tool for handling decentralized storage needs. Additionally, Pinata, a service built on top of IPFS, was used for easier management and pinning of IPFS data.

Hardhat, an Ethereum development environment, was another key tool. It facilitated the compilation, deployment, testing, and debugging of Ethereum software. Notably, Hardhat includes an in-memory blockchain environment – the Hardhat Network – which mimics a production-like environment for development purposes. This feature is particularly important for testing how code behaves in real-world scenarios.

Solidity, the programming language for writing smart contracts on the Ethereum blockchain, was central to the development process. Solidity's syntax and capabilities allowed for the creation of robust and secure smart contracts, which are fundamental in decentralized applications.

OpenZeppelin's smart contracts were also utilized. These community-vetted smart contracts are crucial for developing decentralized applications, especially on the Ethereum blockchain. They provide a secure foundation, reducing the risk of vulnerabilities and enhancing the overall safety of the smart contracts.

Finally, MetaMask wallets were integrated into the application. MetaMask is a software cryptocurrency wallet that interacts with the Ethereum blockchain. It enables users to access their Ethereum wallet via a browser extension or mobile app, facilitating interactions with decentralized applications. MetaMask's integration ensured seamless transactions and interactions within the blockchain environment.

Together, these tools formed the technological backbone of the real estate application, combining the power of modern web development with the innovative potential of blockchain technology.

6.2 Implementation

6.2.1 User Interface

The application takes the user through the stages a real estate transaction which we broke down as follows in Figure 6.2:

Offer	Inspection	Title Search	Closing
Buyer Offer	Land Survey	Title Search	NFT Transfer
Buyer Approval	Appraisal	Property NFT Minting	Release of Funds
Down Payment			

Figure 6.2: Task table of Role functionality.

Each stage contains a collection of action items. When an action item is completed, the user submits it for approval by other required parties. Items that require an identical set of approvals are placed in the same stage.

Figure 6.3 displays Action Items for users to complete

Each Action Item card displays the item name, description, and approvals needed.

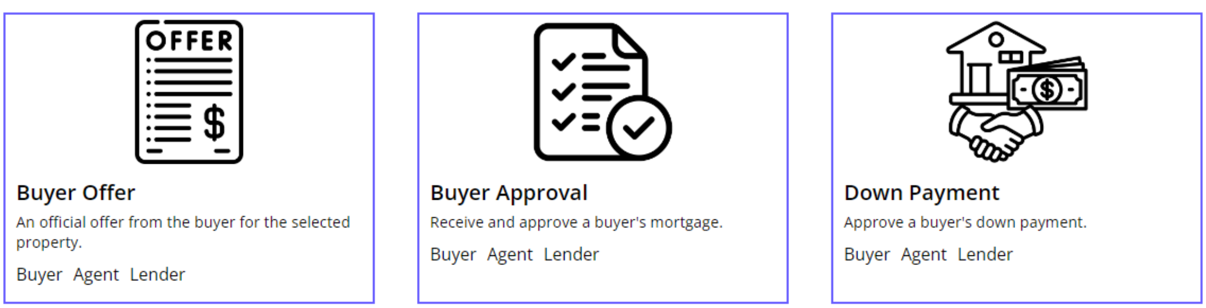


Figure 6.3: Action Items for User Completion.

Figure 6.4 displays the homepage of our application.

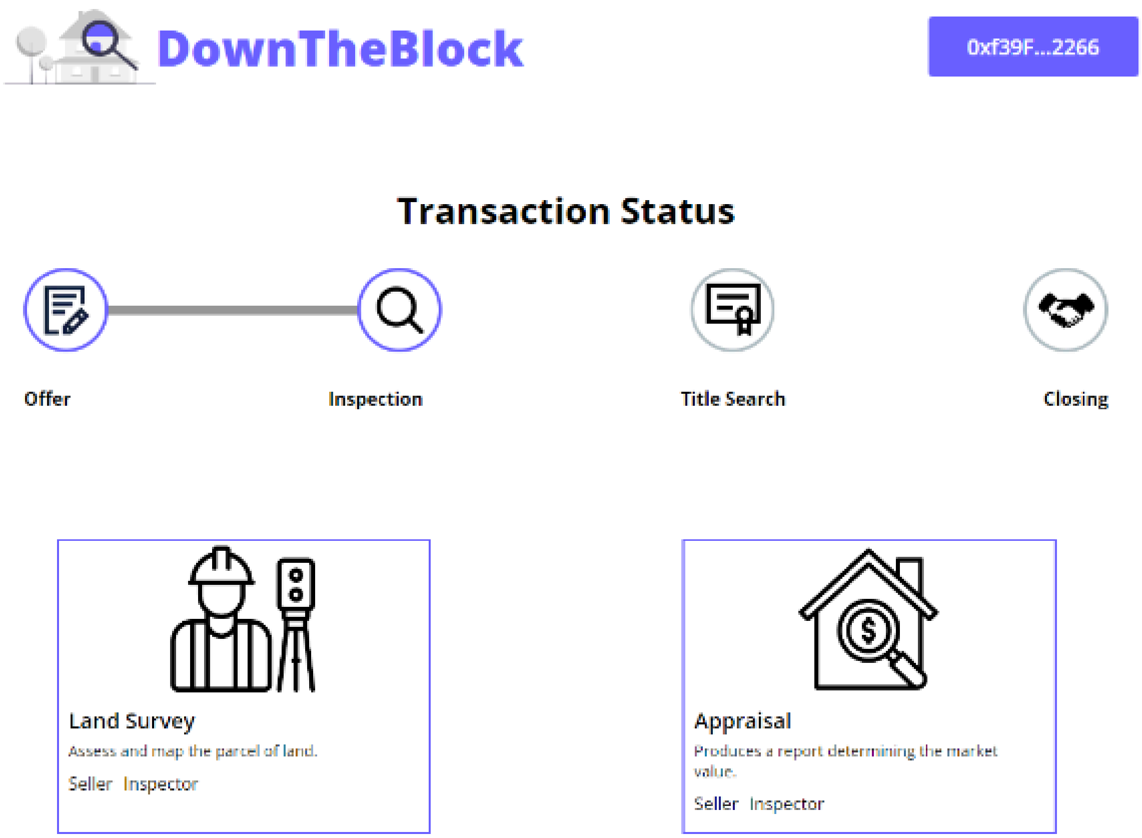


Figure 6.4: Application Home Page.

Figure 6.5 displays the Transaction Status Bar for tracking progress

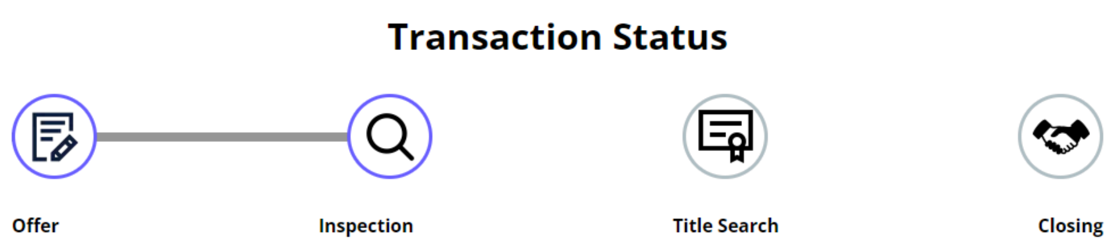


Figure 6.5: Progress Tracker.

Figure 6.6. displays how users connect their MetaMask Wallet

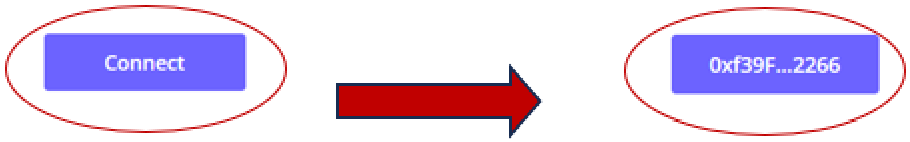


Figure 6.6: MetaMask Account Connection Button.

Figure 6.7 displays a MetaMask Wallet connected to our local network node

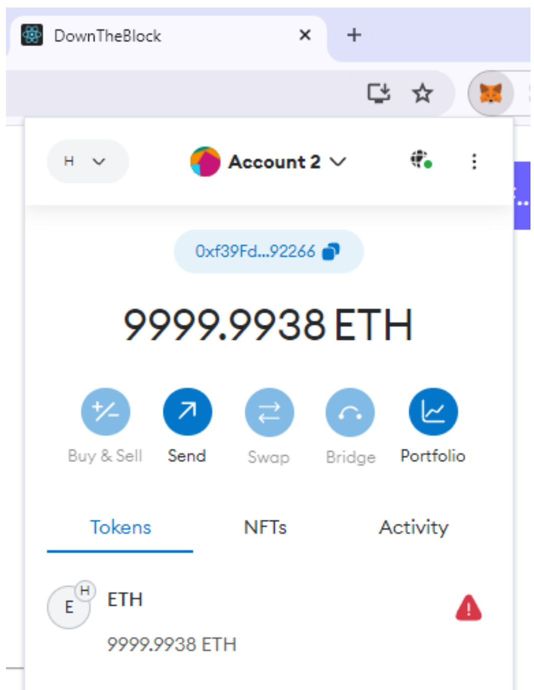


Figure 6.7: Test MetaMask Account Connected to Local Development Server.

Figure 6.8 displays the Action Item view when clicked

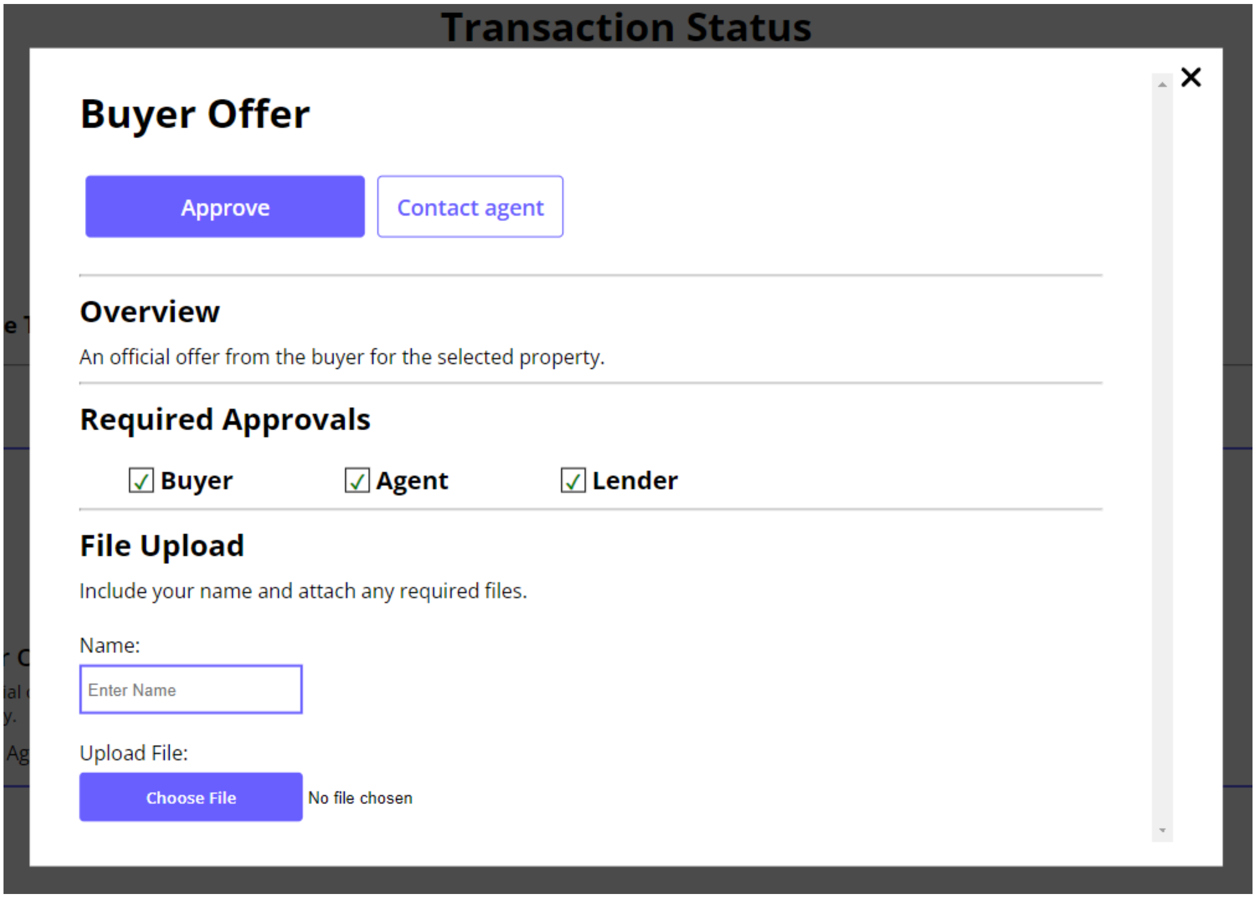


Figure 6.8: Expanded Buyer Offer Action Item.

6.2.2 Action Item Implementation

ERC20 Contract

There were several considerations we had to take into account when implementing the action items through a smart contract. The first is that we wanted a way to create a way that items could be stored on the blockchain and without requiring any storage outside of the IPFS. To achieve this, we implemented tokens using OpenZeppelin's ERC20 token standard which allowed us to mint fungible tokens to represent action items to be completed. An example of the mint() function is displayed below in Figure 6.9.

```
constructor() ERC20("ActionItem", "ITEM") {}

function mint(string memory tokenURI) public returns (uint256) {
    _tokenIds.increment();

    uint256 newItemId = _tokenIds.current();
    _mint(msg.sender, newItemId);
    _setTokenURI(newItemId, tokenURI);


    return newItemId;
}
```

Figure 6.9: Solidity mint() function.

Pinata File Service

These items were stored using Pinata in the form of a json document, as shown in Figure 6.10. This allows for items to be added or removed outside the application while managed on IPFS.

```
{
    "name": "Buyer Offer",
    "description": "An official offer from the buyer for the selected property.",
    "id": "1",
    "authorized_users": ["Buyer", "Agent", "Lender"],
    "image" : "https://ipfs.io/ipfs/QmVxujpDah6DxuGHLsNNirCU3SunkWbVzqv2PWpFStQomj/offer.png",
    "stage" : "Offer"
}
```

Figure 6.10: JSON format.

Deploy.js

In order for our app to be able to interact with this data it needs to be deployed to our local hardhat node using a script separate from the rest of the application, shown in Figure 6.11.

```
// Deploy Action Items
const ActionItem = await ethers.getContractFactory('ActionItem')
const actionItem = await ActionItem.deploy()
await actionItem.deployed()

console.log(`Deployed Action Item Contract at: ${actionItem.address}`)
console.log(`Minting 9 action items...\n`)


for (let i = 0; i < 9; i++) {
  const transaction = await actionItem.connect(seller).mint(`https://ipfs.io/ipfs/QmWC6TzTrsWVVYLYDAeGM4HJE65AeL67i3MJ
  await transaction.wait()
}
```

Figure 6.11: Deploy script code snippet.

ERC20Permit Contract

Another consideration we had was that these approvals should not require the user to hold ETH to be able to 'sign' an approval in the app. So to support that we used the ERC20Permit Contract. With this contract, users can approve without the need of sending a transaction.

6.2.3 Access Control

One of the challenges we aimed to tackle with this project was that of managing access control in blockchain applications. With real estate specifically we aimed to have the app support action items with varying required approvals. For example in the 'Offer' stage, a buyer needs a sign off from a lender to make an offer official. But in the 'Closing' stage only the Seller's approval is needed. We implemented our Access Control as follows.

AccessControl.sol

OpenZepplin's AccessControl.sol was used as the primary method of supporting role based access control in our application. AccessControl.sol supports modifiers that prevent anyone that lacks the required role from being able to access a specific function. This process is shown below in Figures 6.12 and 6.13.

```
// Modifiers for restricting functionality based on a given role
modifier onlyBuyer() {
    require(hasRole(BUYER_ROLE, msg.sender), "Error: Caller does not have the Buyer Role!");
    _;
}

modifier onlySeller() {
    require(hasRole(SELLER_ROLE, msg.sender), "Error: Caller does not have the Seller Role!");
    _;
}
```

Figure 6.12: Example of a role modifier definition.

```
// Buyer Functionality

function buyerApproval(uint _id) public onlyBuyer {
    require(
        items[_id].status == Status.Lender_Approved,
        "Item must be approved by the Lender first"
    );
    items[_id].status = Status.Approved;
}
```

Figure 6.13: Example of a role modifier being used.

Granting Roles using Ownable.sol

To have flexibility in role assignment we used the Ownable.sol contract to allow for roles to be granted and revoked, this functionality is visualized in Figure 6.14.

```
// Buyers
function grantBuyerRole(address account) external onlyOwner {
    _grantRole(BUYER_ROLE, account);
}

function revokeBuyerRole(address account) external onlyOwner {
    _revokeRole(BUYER_ROLE, account);
}
```

Figure 6.14: Smart Contract owner functionality for granting roles.

6.3 Feedback & Commentary

6.3.1 Feedback

To get feedback on our work we conducted an interview with a real estate expert based in Worcester, Massachusetts. The interview aimed to explore the expert's perspectives on the potential integration of blockchain technology within the real estate sector, focusing on its applicability and the limitations it faces concerning current practices.

The participant acknowledged the real estate industry's archaic nature, describing it as predominantly "paper-driven." Despite recognizing the theoretical benefits of blockchain, such as its ability to represent property ownership through digital deeds, the expert expressed skepticism regarding its widespread adoption within the industry. They highlighted several reasons for this outlook, including:

Skepticism About Eliminating Traditional Services: The professional doubted blockchain's capability to obviate the need for established services like title insurance, suggesting that such a shift would require a profound restructuring of existing practices.

Perceived Transparency of Current Transactions: Contrary to the common narrative that blockchain could significantly enhance transaction transparency, the interviewee argued that real estate transactions are already sufficiently transparent. They posited that any notable improvement in this area would necessitate a comprehensive overhaul of the industry's transactional processes.

The insights from the interview indicate a cautious stance towards the integration of blockchain technology in real estate. While the potential for digital representation of property ownership was acknowledged, the expert's perspective underscores the challenges of disrupting entrenched industry practices. This resistance suggests a broader reluctance within the sector to depart from traditional methodologies, even in the face of technological advancements promising increased efficiency and transparency.

6.3.2 Commentary

Web3 technologies herald a transformative era in application development, offering unprecedented capabilities that were either non-existent or arduous to implement in the Web 2.0 paradigm. However, the feasibility of constructing comprehensive applications solely on this new technology platform remains an area of debate.

AccessManager

In October 2023, OpenZeppelin unveiled the AccessManager contract, an advancement over its predecessors, AccessControl.sol and Ownable.sol. This innovation facilitates developers in implementing granular access control on a many-to-many basis, addressing a notable development challenge within the decentralized application (dApp) ecosystem. Prior to this release, our development efforts were constrained to using AccessControl for managing a role-based system, inadvertently underscoring the rapidly evolving landscape of Web3 technologies and the imperative need for continual adaptation.

IPFS Challenges and Attempted Use of ERC721

Our journey into Web3 application development was marked by several challenges, notably the inconsistent reliability of InterPlanetary File System (IPFS) services. The fluctuating performance, ranging from optimal operation to complete timeouts, highlighted the unpredictable nature of relying on decentralized storage solutions. Furthermore, our endeavor to integrate

Non-Fungible Tokens (NFTs) using the ERC721 standard revealed intrinsic limitations, particularly in facilitating scalable access control, given the exclusive control mechanism inherent to this token type. This experience illuminated the nuanced trade-offs between immutability and functional flexibility in Web3 applications.

Exploration of NFTs for Property Ownership

The concept of utilizing NFTs to represent real-world property ownership emerged as a compelling research avenue. Despite the theoretical potential, practical exploration was stymied by our limited domain expertise and the complexities involved in translating physical assets into digital tokens. This area, however, remains ripe for investigation, promising to bridge the tangible and digital realms in unprecedented ways.

7. Supply Chain Management

7.1 Design

One of the biggest challenges faced in supply chain management is the problem of counterfeited goods. In a joint collaboration study conducted by the Organisation for Economic Co-operation and Development (OECD) and the EU Intellectual Property Office (EUIPO) in 2021, they found that up to 2.5% of world trade in 2019 consisted of counterfeit and pirated goods (OECD/EUIPO, 2021). The percentage further jumps up to 5.8% when only considering imports from the EU. And according to the World Trade Organization's report in 2019, the global export value of traded goods in 2019 was valued at approximately $19 trillion USD (WTO, 2019), and even just 2.5% of that would still be a staggering $475 billion USD. This increasingly broadening issue has potential to undermine innovation and hamper the growth of modern global economies.

One of the most prevalent categories involved in the counterfeit business is luxury goods. There are numerous reports every year of counterfeit goods being seized, with a prominent majority being luxury products; an article from back in March of 2005 covers a story of French customs seizing enough counterfeit Louis Vuitton fabric to cover 54 tennis courts (Laurenson, 2005). Even in recent times, US Customs and Border Protection (CBP) and U.S. Immigration and Customs Enforcement (ICE)-Homeland Security Investigation (HSI) seized 19,522 shipments of goods that violated Intellectual Property Rights in 2023, equating to roughly 23 million counterfeited goods (CBP, 2024). Out of the total seizures, Watches/Jewelry were among the top products in terms of MSRP value, being valued at over $1 billion USD, or 43.4% of the total value seized. Handbags/wallets came in second with a value of $653 million USD, equating to 27.1% of the total. A report conducted in 2019 by Harvard Business Review estimated that 60-70% of the total value of traded fakes were fake luxury merchandise, and that those fakes potentially accounted for a quarter of total trade in luxury goods (Fontana, 2019).

One of the key factors in this increasing trend of counterfeiting is the shift of value to intellectual property (IP). In most modern-day markets, IP represents a key value generator and is one of the biggest enablers of success between competition. However, this shift has created opportunities for others to coast along on other’s intellectual assets with counterfeited products.

Another key factor lies in the complexity of modern supply chains, especially when expanded into a global context. Despite the typical presence of a large central authority, the existence of numerous intermediaries and a global network of manufacturers, distributors, and retailers still present many opportunities for counterfeit goods to enter the system. This complexity often hampers efforts to trace the origins of counterfeit products, and is often magnified by a lack of universal transparency measures within many supply chains. This challenge is only further exacerbated when broadening to a global scale by dispersing production and distribution across multiple countries.

Additionally, a constant drive to reduce costs and maximize profits can lead to compromises in quality control, such as implementing cost-cutting measures that compromise validation integrity, or outsourcing manufacturing to lower-cost regions where counterfeiting may be more prevalent. Figure 3.1 from the study conducted by both the OECD and EUIPO identifies China and Hong Kong as the primary provenance of counterfeit and pirated goods in terms of the number of custom seizures, combining for nearly 75% of the total. Other countries like Turkey and Malaysia contribute to the remaining 25% as well. Interestingly, these countries can all be found towards the top of a US News Report ranking countries by the cheapest manufacturing costs, with India, China, and Vietnam leading the list, and the rest being in the top 30 countries (US News, n.d.).

Lastly, the emergence of what is commonly referred to as “superfakes” has also significantly altered the counterfeit goods industry. In a New York Times article published in 2023, writer Amy Wang included her experience walking around with a fake Celine bag in Paris, where punishments for counterfeiting included prison time, however never once caught any attention. An image provided later showcases just how hard it is to spot these super fakes, with the example being a Chanel handbag, as seen below in Figure 7.1.

Figure 7.1: Left is an authentic Classic Chanel handbag priced at $10,200, with a fake on the right being priced at $390.

Those whose business is to verify these types of luxury goods always say that there is a tell, no matter how insignificant it may be, but one of the authenticators that she interviewed admitted that sometimes there really is no surefire way to tell the difference, and ends up being a tedious egg hunt. (Wang, 2023)

Therefore, enhancing the traceability and transparency of products and their origins within supply chains emerges as a promising strategy to combat the proliferation of counterfeit goods. These desired qualities are coincidentally key features of Web3 technologies, particularly blockchain technology. Because of the decentralized structure of blockchains, the risk of individual nodes being tampered with can be mitigated, as modifications would require altering the ledger across all nodes in a network to remain undetected. By leveraging these inherent attributes of blockchain technology, a unique solution can potentially be developed to help address the inefficiencies in tracking and authentication of goods within supply chains.

7.2 Implementation

The original goal of this application was to create a demo application highlighting how luxury goods could be reliably tracked on a blockchain. The application would be governed by a smart contract on the Ethereum blockchain that would essentially act as a backend for the creation of a product, and its transfer of ownership throughout various actors in the system. However, as initial development was made and the scope of the project was assessed, the application was changed from being focused solely on luxury goods to a general demonstration of the process of moving a product from a manufacturer to a customer through a supply chain while maintaining the integrity of the product through extensive validation and tracking.

For simplicity, three main roles were devised; a Manufacturer role to represent the parties creating the products, a Vendor role to handle the distribution of products received from Manufacturers, and a Customer role to represent the individual consumers. An initial role would be created as the smart contract requires an account to deploy it onto the blockchain. Figure 7.2 lists the functionalities each role would have in the application:

Role	Functionality
Manufacturer	• Produce and ship items to Vendors
Vendor	• Receive goods from Manufacturers • Inspect a product, and have the ability to Approve or Reject it • Sell the product to a Customer
Customer	• Ability to order and purchase a product

	• Ability to cancel a order

Figure 7.2: Functionality of each role in the application.

Figure 7.3 showcases the general flow of the application, and how each role interacts with the blockchain, the smart contracts, and themselves.

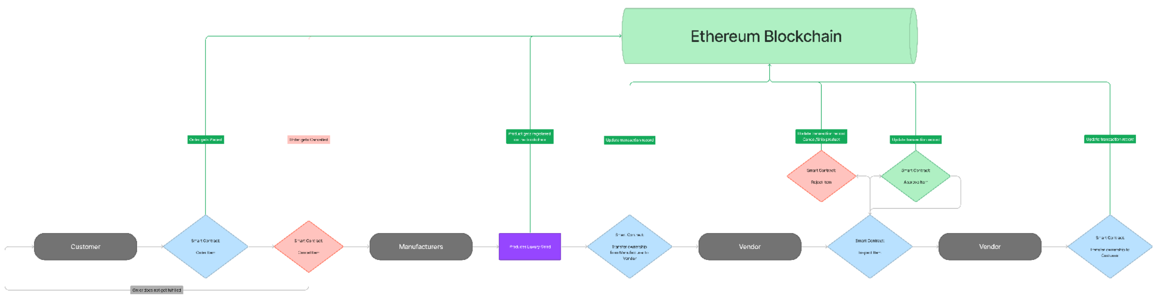


Figure 7.3: General application flowchart.

The following tools mentioned earlier in Section 3 were utilized for this application:

- **Solidity:** The main language used to develop the smart contract.
- **OpenZeppelin:** A Solidity library used to help implement secure access and control of roles in the application.
- **Remix Online IDE:** The online IDE version was used to quickly deploy the resulting smart contract to the Sepolia testnet.
- **MetaMask:** The extension used to connect test crypto wallets to both the Remix IDE compiler and the frontend application for testing.

Additionally, the dApp itself was developed with TypeScript, with GitHub being used as version control. The testnet currency SepoliaETH was acquired from Alchemy's Sepolia Faucet.

A basis for the application was forked from Mesfin Tsegaye's Decentralized Supply Chain Application (Tsegaye, 2023), which represented a simple system of an Owner and Customers. Customers could order an item, and the Owner would ship the order to them. With the additional utilization of an OpenZeppelin contract called AccessControl, additional roles were able to be created to fit the requirements in Figure 7.3. With the addition of AccessControl, functionality can be easily restricted by adding modifiers that check if an incoming account (msg.sender) has the correct role associated as seen below in Figure 7.4.

```
// Modifiers for restricting functionality based on a given role
modifier onlyManufacturer() {
    require(hasRole(MANUFACTURER_ROLE, msg.sender), "Error: Caller does not have the Manufacturer Role!");
    _;
}
```

Figure 7.4: Manufacturer role check.

Figure 7.5 shows how the modifiers can be used to restrict access to functionality; in this case, since only Manufacturers can ship items to Vendors, the modifier is put into place to ensure no other non-authorized Manufacturers can send an item.

```
function shipItem(uint _id) public onlyManufacturer {
    require(
        items[_id].status == Status.Ordered,
        "Item must be in Ordered state to be shipped to Vendor"
    );
    items[_id].status = Status.Shipped;
    items[_id].createdBy = msg.sender;
}
```

Figure 7.5: Example use case of the modifier.

Similar modifiers were used for the other roles, and once final checks of the smart contract were passed, the contract was deployed to the Sepolia network through Remix's online IDE.

As mentioned earlier, the dApp (frontend) portion was developed with TypeScript. With the generated ABI file obtained from compiling the smart contract on Remix IDE, an user-interface can be created to intuitively interact with the smart contract. A capture of the dApp can be seen in Figure 7.6. Users have the option to connect their MetaMask wallet through either the button in the top right, or through the default Metamask browser extension popup. Customers have the ability to enter an item to be ordered, and all users have the ability to search an item by ID, displaying its status as well as the addresses that have interacted with the product. A table immediately below the input fields displays all products currently existing on the smart contract, and include the following attributes:

1. Product ID,
2. Product name,
3. Order status,
4. Address of the Customer that ordered the product,
5. Address of the Manufacturer that created the product,
6. Address of the Inspector (for the scope of this project, they are equivalent to the Vendor)
7. Address of the Vendor that ships the item to the Customer, and
8. Action items.

Action Items correspond to functionalities that different roles have and include the following:
- Create: Manufacturer creates the item and ships it to a Vendor for inspection.
- Cancel: Option for User to cancel their order before the product gets created.
- Approve Item/Reject Item: Vendor can inspect the product and approve or reject it.
- Ship Item: Vendor can ship the item to the Customer, completing the order.

While the choice was made to have the Action Items appear regardless of what roles a current account may have, attempting to use an Action Item without the proper authorization results in the transaction failing and an error message popping up informing of the invalid access as seen in Figure 7.7.

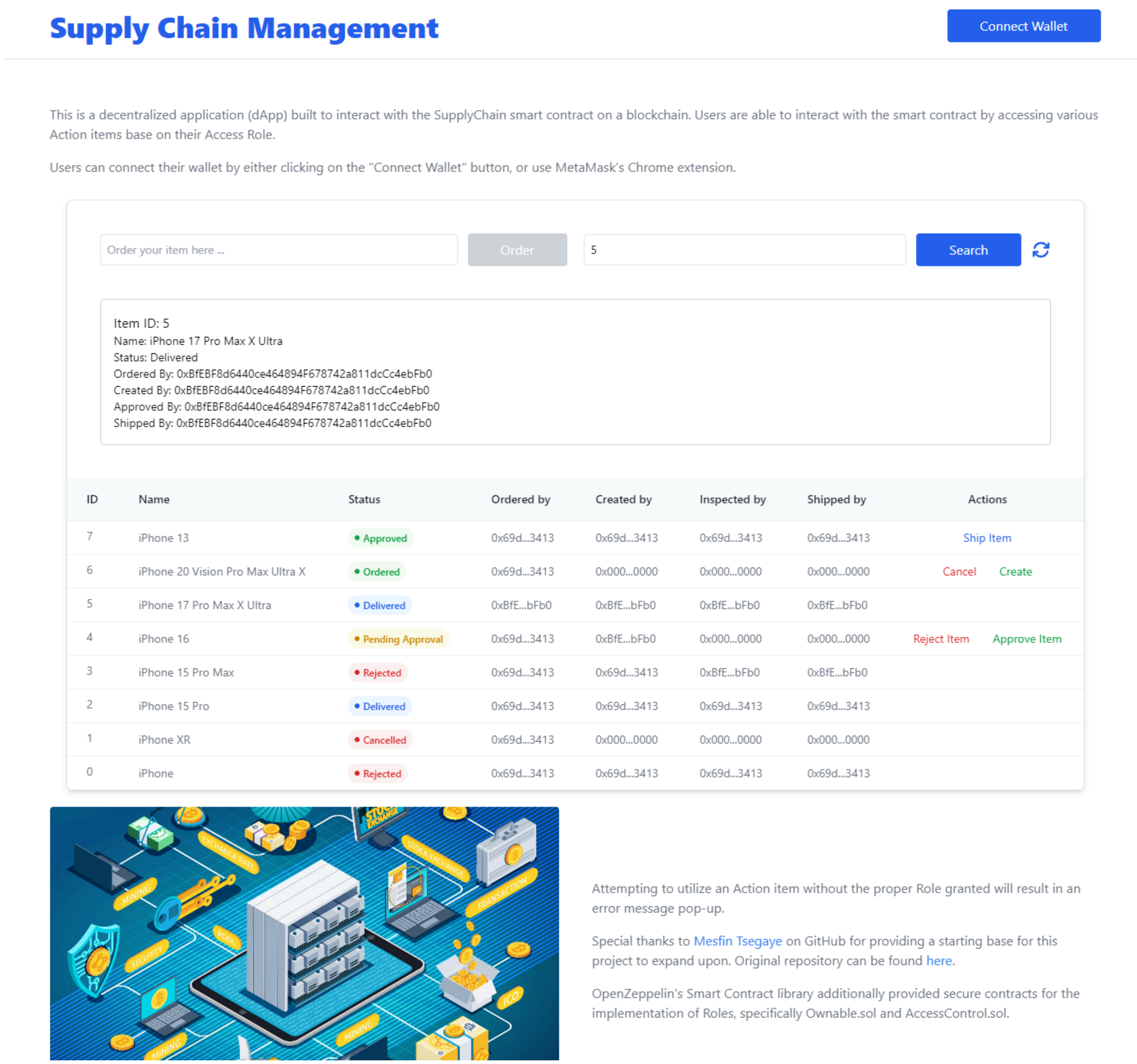


Figure 7.6: dApp with test objects created and in various statuses.

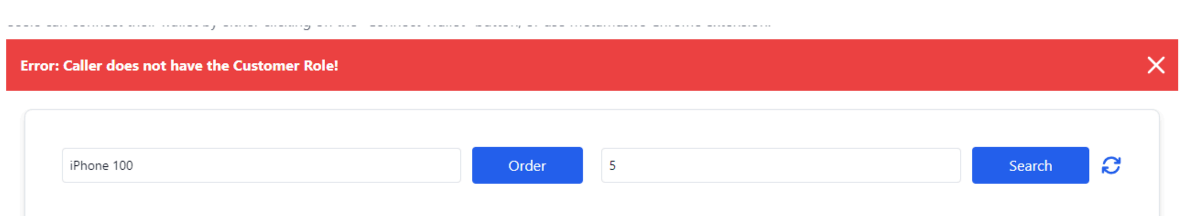
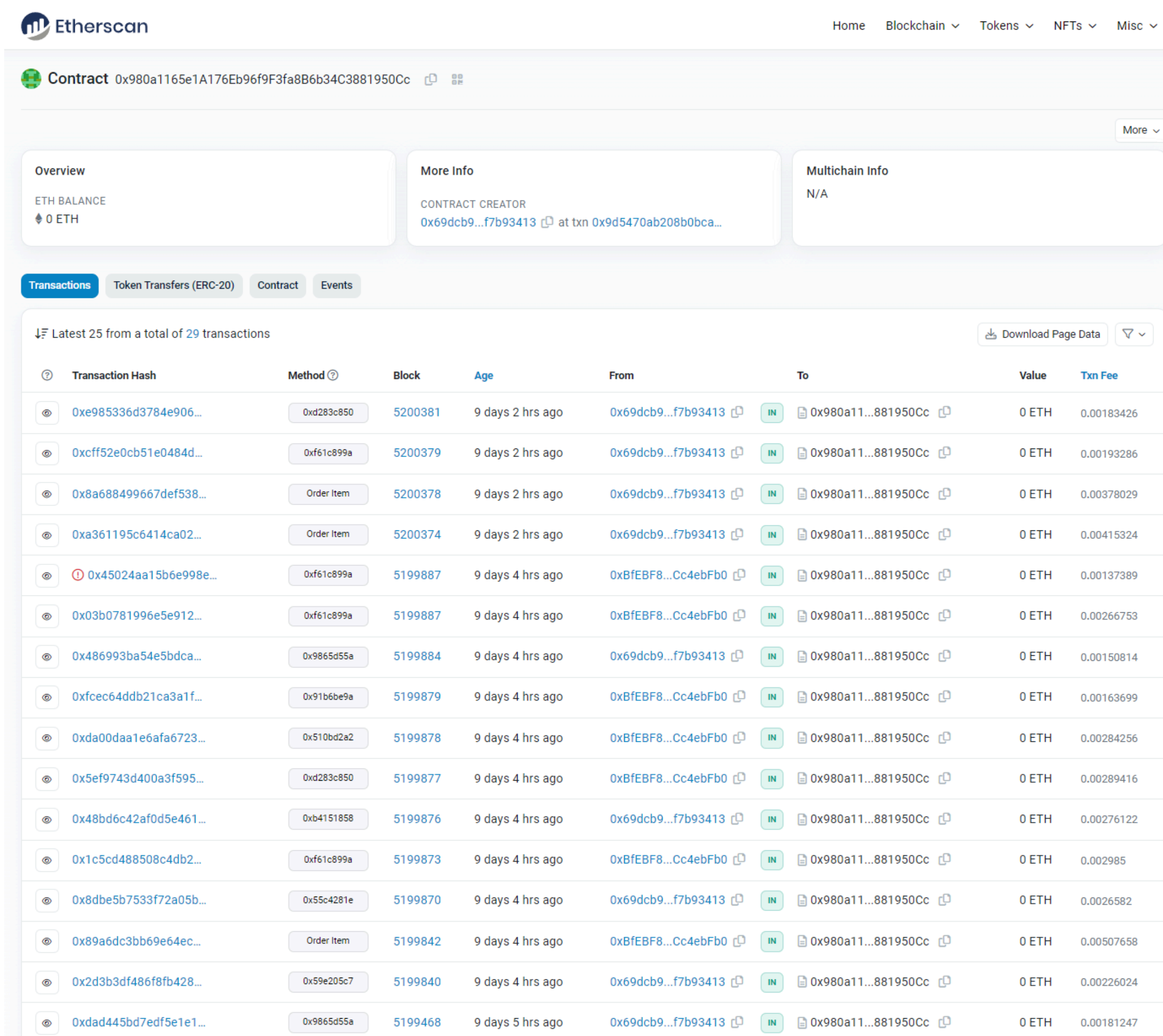


Figure 7.7: Example of a failed attempt to order an item without the Customer role.

Public websites such as Sepolia.Etherscan.io additionally provide user-interfaces for examining transaction history on the Sepolia testnet. Users are also able to filter by specific addresses, and a snapshot of the transaction history of the deployed smart contract can be seen in Figure 7.8, which was taken after the current state of the smart contract portrayed in Figure 7.6 earlier.



Transaction Hash	Method	Block	Age	From		To	Value	Txn Fee
0xe985336d3784e906...	0xd283c850	5200381	9 days 2 hrs ago	0x69dcb9...f7b93413	IN	0x980a11...881950Cc	0 ETH	0.00183426
0xcff52e0cb51e0484d...	0xf61c899a	5200379	9 days 2 hrs ago	0x69dcb9...f7b93413	IN	0x980a11...881950Cc	0 ETH	0.00193286
0x8a688499667def538...	Order Item	5200378	9 days 2 hrs ago	0x69dcb9...f7b93413	IN	0x980a11...881950Cc	0 ETH	0.00378029
0xa361195c6414ca02...	Order Item	5200374	9 days 2 hrs ago	0x69dcb9...f7b93413	IN	0x980a11...881950Cc	0 ETH	0.00415324
0x45024aa15b6e998e...	0xf61c899a	5199887	9 days 4 hrs ago	0xBfEBF8...Cc4ebFb0	IN	0x980a11...881950Cc	0 ETH	0.00137389
0x03b0781996e5e912...	0xf61c899a	5199887	9 days 4 hrs ago	0xBfEBF8...Cc4ebFb0	IN	0x980a11...881950Cc	0 ETH	0.00266753
0x486993ba54e5bdca...	0x9865d55a	5199884	9 days 4 hrs ago	0x69dcb9...f7b93413	IN	0x980a11...881950Cc	0 ETH	0.00150814
0xfcec64ddb21ca3a1f...	0x91b6be9a	5199879	9 days 4 hrs ago	0xBfEBF8...Cc4ebFb0	IN	0x980a11...881950Cc	0 ETH	0.00163699
0xda00daa1e6afa6723...	0x510bd2a2	5199878	9 days 4 hrs ago	0xBfEBF8...Cc4ebFb0	IN	0x980a11...881950Cc	0 ETH	0.00284256
0x5ef9743d400a3f595...	0xd283c850	5199877	9 days 4 hrs ago	0xBfEBF8...Cc4ebFb0	IN	0x980a11...881950Cc	0 ETH	0.00289416
0x48bd6c42af0d5e461...	0xb4151858	5199876	9 days 4 hrs ago	0x69dcb9...f7b93413	IN	0x980a11...881950Cc	0 ETH	0.00276122
0x1c5cd488508c4db2...	0xf61c899a	5199873	9 days 4 hrs ago	0xBfEBF8...Cc4ebFb0	IN	0x980a11...881950Cc	0 ETH	0.002985
0x8dbe5b7533f72a05b...	0x55c4281e	5199870	9 days 4 hrs ago	0x69dcb9...f7b93413	IN	0x980a11...881950Cc	0 ETH	0.0026582
0x89a6dc3bb69e64ec...	Order Item	5199842	9 days 4 hrs ago	0xBfEBF8...Cc4ebFb0	IN	0x980a11...881950Cc	0 ETH	0.00507658
0x2d3b3df486f8fb428...	0x59e205c7	5199840	9 days 4 hrs ago	0x69dcb9...f7b93413	IN	0x980a11...881950Cc	0 ETH	0.00226024
0xdad445bd7edf5e1e1...	0x9865d55a	5199468	9 days 5 hrs ago	0x69dcb9...f7b93413	IN	0x980a11...881950Cc	0 ETH	0.00181247

Figure 7.8: Etherscan of transactions made to the deployed smart contract.

7.3 Feedback & Commentary

To assess the effectiveness of the demo application and the potential of Web3 in supply chain management, an interview was conducted with Professor Joseph Sarkis from the School of Business at Worcester Polytechnic Institute (WPI). Throughout the interview, several key factors were brought up, both regarding the specific aspects the demo application addressed, as well as broader issues that exist in the integration of these technologies into modern day supply chains.

One clear advantage that was identified was the increased visibility of data that consumers can access. Thanks to public sites like EtherScan, users interacting with dApps can easily see and search up all transactions at the given address thanks to blockchains keeping that immutable ledger. As seen in Figure 7.8 earlier above, each transaction has its own identifying hash, provides the addresses of the parties involved in the transaction, and can even show what function was run on the smart contract. This gives the ability for users to verify that their product passed through the blockchain without any suspicious modifications made in the process.

However, one of the biggest topics discussed during the interview were the so-called "barriers" that prohibit the seamless integration of these technologies into modern day supply chains.

One concern was related to the fact that all transactions that occur on a blockchain are inherently public, as the ledger logs all transactions made. Workarounds do seem to exist that can help mask a wallet or address trace, but the transaction still inevitably appears in the history. Professor Sarkis brought up a point that companies may be unwilling to adapt because of this property. A key aspect of supply chain management is the management of relationships among partners to create value for stakeholders (Lambert, 2017). And while information transparency is crucial for verifiability (Sarkis, 2018), this would force companies to potentially divulge valuable and critical information that they may deem as a competitive advantage. Rival companies could potentially sort through the transaction history to identify where others source materials from, or determine negotiated prices on specific components

Another concern brought up by Professor Sarkis was the validity of information entering the blockchain network. During the demonstration of the supply chain application, we concluded that the data transferred in the blockchain was secure as verified by the EtherScan. Earlier in Figures 7.7 and 7.8, a sample order was placed for an iPhone 13, and Figure 7.9 below shows that specific order item function transaction initiated by the test account to the deployed smart contract.

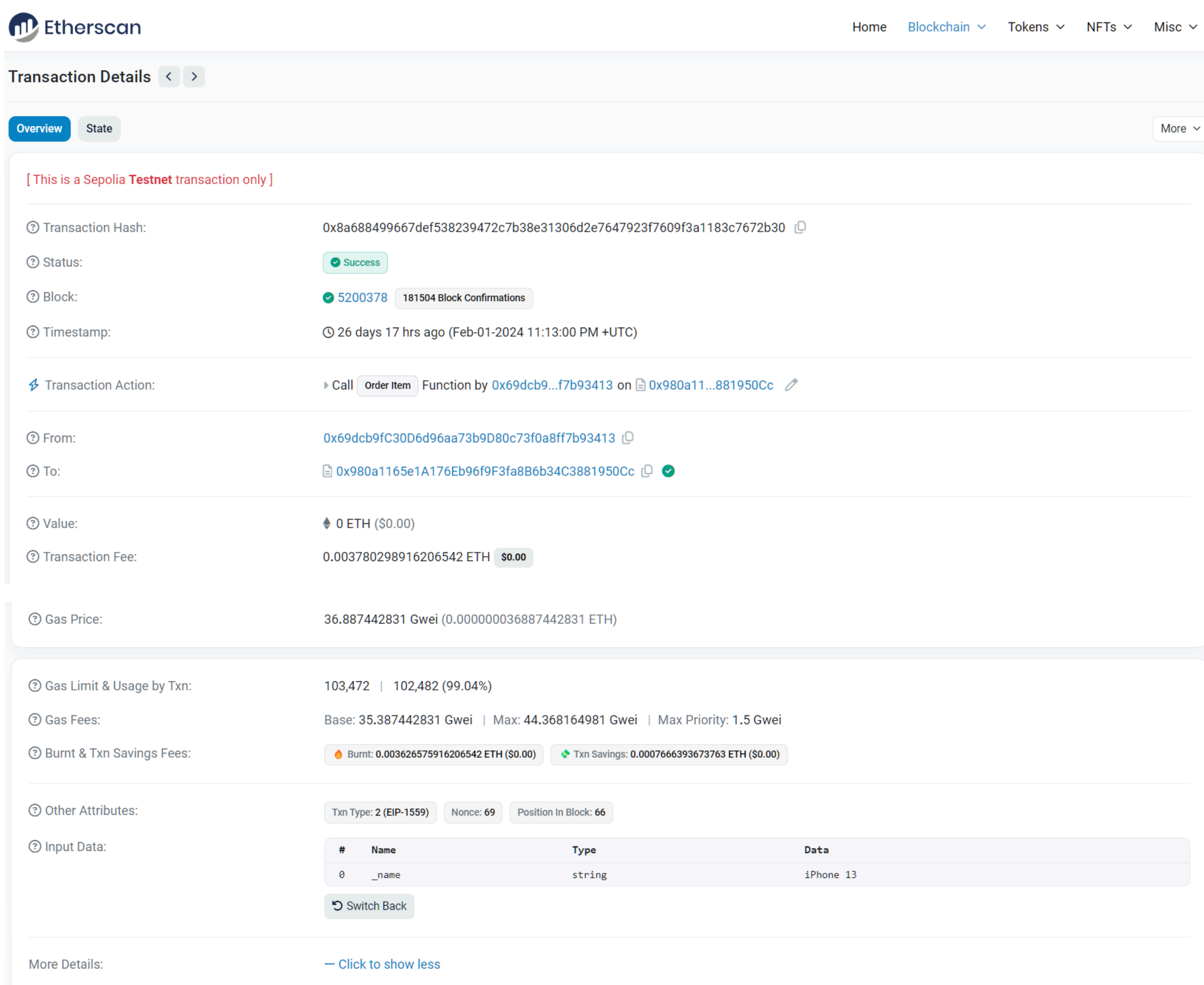


Figure 7.9: Specific transaction record.

All that data remains the exact same and exists indefinitely until the Sepolia testnet gets deleted permanently, but the primary concern was that there was this confidence that the authenticity of the data exists only in the internal data. External data uploaded into the blockchain can still be suspect to errors.

Beyond the topics covered during the interview, another topic that was touched upon earlier in Section 7.1 was the constant need to reduce supply chain costs to maximize profits. One of the most prevalent costs in a blockchain is the cost of executing functions and transactions. While Ethereum gas prices are measured in extremely small units of GWEI, current transaction costs in the demo application on Sepolia roughly equate to a couple USD dollars, whose test environments attempt to accurately simulate the conditions of the Ethereum mainnet. With how large most supply chains are, these small transaction fees, which still work out to almost a couple USD, will ramp up significantly.

It is therefore important to take away from this interview and demo application that blockchain technology, while providing promising benefits, is unable to be the sole solution to challenges faced in modern-day supply chains. It may be used as a crucial component, but there may likely be a need for additional tools to be integrated, such as auditors to verify external data being uploaded into the network. Blockchain technology is still undergoing numerous improvements in the efficiency of storing data and maximizing the possible number of transactions per second, which are crucial to keeping transaction fees at a minimum.

8. Discussion

Our project embarked on an exploratory journey into the realm of Web3, focusing on its potential to revolutionize industries through decentralization, blockchain technology, and the integration of NFTs. Throughout our work, we aimed to not only understand the current landscape of Web3 applications, but also to identify areas where this emerging technology could offer significant improvements over traditional systems. To help evaluate our devised solutions, experts in the respective sectors were interviewed.

In this section, we first discuss the limitations and blockers discovered that still prevent Web3 technology from already becoming integrated globally. Then we take a look at the overall consensus of Web3's potential.

8.1 Commonalities Across Application Development

While Web3 technology has made great strides since the first coining of the term in 2014, it is clear from the experiences of this project that there is still a ways to go before any real integration efforts can be made.

8.1.1 Industry Adoption Cost

As discussed earlier in Section 7.3, Professor Sarkis pointed out that the primary blocker behind the general adoption of Web3 technology lies in the organizations. While consumers acquire several benefits from this technology, there exist several barriers that prohibit organizations from similarly jumping onto the trend. In a paper provided during the interview, Professor Sarkis and other professors at the School of Business at WPI embarked with the goal to be one of the first papers that clearly identified and categorized blockchain adoption barriers. By reviewing relevant literature, they developed a diagram to help summarize their findings, which is included below in Figure 8.1.

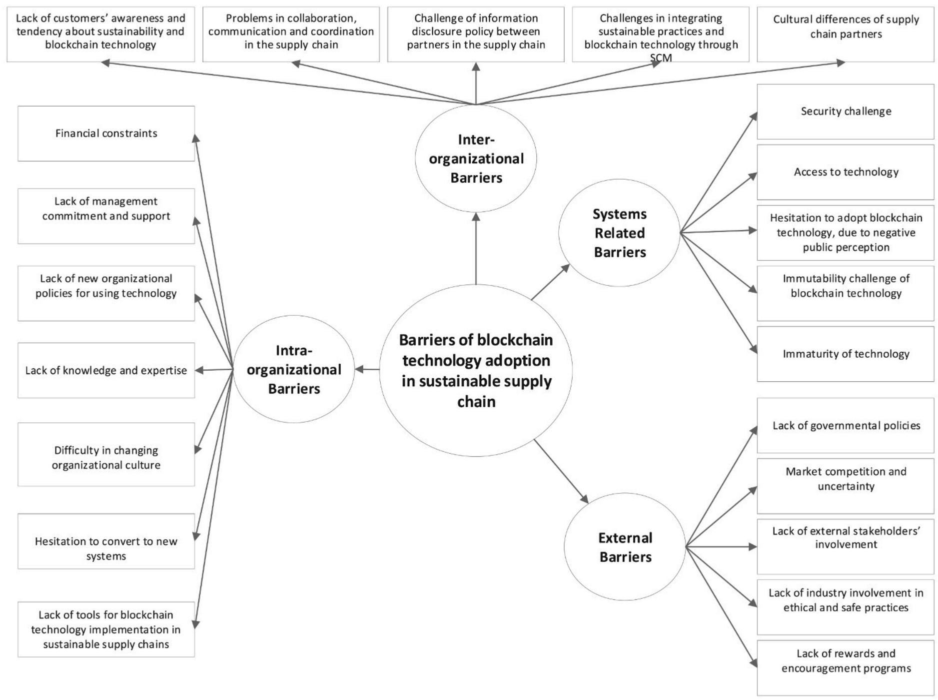


Figure 8.1: Summary of barriers in blockchain adoption (Saberi, 2019).

In general, the researched barriers were categorized into four main groupings: internal activities in organizations, relationships between partner organizations, system-related technological barriers, and additional external barriers.

A barrier both identified in the paper and realized throughout the development of our applications was the cost of adopting Web3 technology, primarily the utilization of blockchains as an alternative solution. One key issue is the ever-changing state of blockchain technology, such as the numerous upgrades and procedure changes that Ethereum has gone through, in both its mainnet and testnets. These issues are elaborated upon in Section 8.1.2.

Another issue with the adoption of Web3 technology is a lack of current expertise knowledge, as it represents a significant shift in development standards present in Web 2.0-based applications. Technologies such as smart contracts and smart wallets display similarities to general backend infrastructure and login systems. However, principles such as decentralization and an emphasis on P2P-based transactions are essentially completely new concepts and require a base of knowledge to be rebuilt upon. Organizations would therefore have to invest significant resources to develop the expertise needed to operate in these new technologies, as well as progress the maturity of IT tools and software. Additional examples of development tools in their infancy stages are described in Section 8.1.2.

Lastly, a key issue brought up during the interview was the inevitable existence of the human factor. Because we are still involved in the application of this technology, there exists the possibility of erroneous data being recorded and uploaded into the blockchain. While the immutability of blockchains guarantees the validity of information contained in a blockchain, erroneously uploaded data will as a result leave a permanent scar. Discussed solutions mainly included an integration of auditors at some stage of the process, whether it be through automated blockchain technologies, or the integration of third party organizations for auditing data.

8.1.2 Infancy of Development Tools

One of the most significant hurdles currently in Web3 development is the constantly changing state of its tools and frameworks. As mentioned earlier in Section 3.1, Ethereum's own blockchain has undergone several iterations of both the mainnet and the testnets. Since its inception, Ethereum has changed its consensus mechanisms for processing transactions from Proof-of-Work to Proof-to-Stake in 2022, which fundamentally changed how transactions are processed. In the old Proof-of-Work model, block creators were referred to as miners because they expend computational resources to solve an encrypted hexadecimal number in return for cryptocurrency. In a proof-of-stake model, block creators are instead called validators, where validation is instead done by offering cryptocurrency as collateral (Nevil, 2023). Additionally as mentioned in Section 3.1, there have been several testnets deployed throughout the years, each with new capabilities and technologies to be tested.

Blockchains also face the issue of scalability, with Ethereum in particular being a focus as they are one of the largest blockchain networks currently active. Because of this, they constantly face the pressure of developing and innovating more efficient procedures while continuing to expand the capacity of their network. During the testing of our deployed applications onto the Sepolia testnet, current gas prices resulted in each interaction with the smart contract having a transaction fee equivalent to a few USD. As defined in Section 2.4, while the gas quantities for transactions are calculated and defined in Ethereum's yellow paper (Wood, 2024), the cost per gas unit depends on the overall efficiency of the network in handling congestion and complex operations. And with Ethereum's testnets created to replicate the mainnet environment without the financial burden, these high gas costs become a major deterrent for supply chain networks that likely require an enormous volume of transactions, where singular transactions costing a few dollars quickly accumulate to result in an unsustainable model.

As mentioned earlier, Ethereum is in a constant state of development, and one future upgrade that intends to improve the efficiency of data storage is named the Dencun upgrade, set to be activated on the mainnet in March 2024 (Hamid,2024). This change will supposedly reduce the cost of transactions by around 80% to 90%. However, it only acts as a short-term solution. Overall capacity of the network is still a prevalent issue, and proposed solutions such as multi-chains can help offload transactions from the mainnet into what is known as appchains, or application-specific blockchains, which can be built on top of a larger mainnet (Werkheiser, 2022). These changes are crucial, as supply chain networks require significantly more data beyond financial transactions to operate, such as those related to processes and practices (Saberi, 2019).

Beyond the constant iterations of blockchains, it was made apparent during the development of the Web3 game that the tools required to effectively incorporate Web3 into games were also still in their infancy stages. For instance, Singularity did not have any support for Unity as of March 2024 despite the fact that Unity has over 1.3 million active monthly users as of March 2023 (Dealessandri, 2023). Although this is not a major setback due to their focus on implementing their Web3 technologies into Unreal Engine, it shows that there is still time needed before the SDK could be fully incorporated into a wider variety of projects. However, one upside is that the SDK still receives frequent updates, with the last one as of writing this paper being an update 10 hours ago (Neobrix, 2024). Our team's experience with Emergence was a similar story. Open Meta and Emergence SDK have an active Discord server where consistent updates have been posted within the past year. Emergence does offer support for both Unity and Unreal Engine, however their Unity SDK is underdeveloped with less documentation compared to its Unreal counterpart. Along with this, one of the features found in the current version of the UI titled “Marketplace” is unable to be viewed. When hovering over the button, there is a pop up that exclaims that it is “coming soon”, as shown in Figure 8.2.

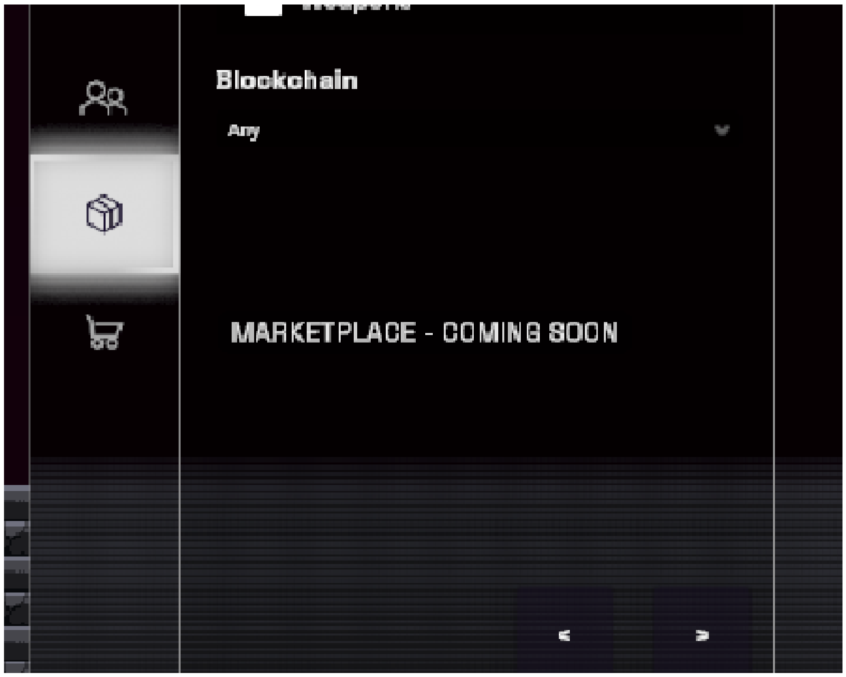


Figure 8.2: In the current version of the Emergence SDK UI “Marketplace” is still “coming soon” and is unable to be accessed.

Overall, we found that SDK’s which allow games to have simpler access to Web3 are still in their infancy stage, with listed features that are yet to be accessible. This constant state of flux presents a unique challenge for developers, who must remain agile and adapt to new tools and standards as they emerge.

8.1.3 User Acceptance of Decentralized Applications

DApps represent a departure from traditional application development, introducing unique schemas centered around blockchain technology. These schemas redefine user interaction, data management, and the very foundations of application architecture.

At the heart of dApp development is the wallet-centric design approach. Unlike traditional applications, where user accounts are typically managed through a centralized database, dApps rely on digital wallets to manage identities and transactions. This shift necessitates a rethinking of user authentication, data security, and interaction patterns, placing the user's wallet at the core of the application experience.

For the Web3 game that we developed, the consensus was overall negative, with the primary concern being how it worsens the player's game experience. Players are forced to connect their wallet through the Emergence interface to interact with the persona system. This process was deemed inconvenient by testers, as it requires the player to download the MetaMask app, create an account if they have not already, scan a QR code, sign in to MetaMask, then accept the smart contract which connects the account to the game. When the majority of games allow the player to access their inventory with the push of a single button, having all these steps for the sole purpose of utilizing the blockchain is just not worth the added hassle for players.

The requirement to have some cryptocurrency in one's wallet is also an issue. While a testnet was used for the purposes of our application, it is more likely that Web3 games will either use Ethereum's Ether or the currency used by the chosen blockchain. This once again leads to the same issue of taking players out of the experience as they now have to spend real world money to obtain cryptocurrency. And when there are plenty of ways to do what our game has done without a blockchain, the blockchain features added seemingly just become another way to make money. All of our testers expressed concern for how cryptocurrency is used in the game, with all of them expressing their desire to remove the crypto and monetary aspects from the game. While there was some positive sentiment about how blockchain technology's decentralized nature could be used as a backend method for storing data, there is a clear desire to lessen the need of cryptocurrency in current applications if it is to ever succeed in the gaming space. Of course, this is easier said than done. Although, with Web3 technologies still being in their infancy, there is plenty of room to grow and improve. It is entirely within the realm of possibility that Web3 will become a positive influence on gaming in the near future.

8.2 Limitations

The exploration of Web3 technologies across multiple industries, while insightful, encounters several limitations that warrant acknowledgment. One of the primary constraints is the inherent rapid evolution of blockchain technology and its tools and frameworks. The fast-paced evolution of Web3 innovations means that our research might not capture the latest advancements or emerging challenges within the sectors of gaming, real estate, healthcare, and supply chain management. This dynamic landscape requires continuous monitoring and updating of information to stay relevant, which our study's static nature cannot fully address.

Another significant limitation is the depth of industry-specific analysis. While our study provides an overview of potential Web3 applications in selected industries, it lacks detailed case studies or empirical data to substantiate the projected benefits and challenges of implementing these technologies. For instance, the theoretical advantages of blockchain in enhancing transparency and efficiency in real estate transactions are discussed without providing concrete examples or data on its practical implementation and outcomes. This gap highlights the need for further research that includes pilot projects, user feedback, and quantitative analyses to more accurately assess the impact of Web3 technologies.

Moreover, our study's scope is limited by the selection of industries and the specific Web3 capabilities explored. The focus on particular sectors and applications may overlook other industries where Web3 could have a significant impact or different blockchain functionalities that could offer novel solutions to existing problems. Additionally, the research does not fully address the regulatory, technical, and societal challenges that accompany the adoption of Web3 technologies, such as legal frameworks, scalability issues, and public acceptance. These limitations suggest avenues for future research to provide a more comprehensive and nuanced understanding of Web3's potential across the global economy.

9. Conclusions & Future Work

9.1 Conclusions

Our exploration into the realm of Web3 technology across various sectors—gaming, real estate, and supply chain management—has illuminated both the transformative potential and the pragmatic challenges of adopting these technologies. The decentralization, transparency, and security offered by Web3 and blockchain technology present compelling advantages for industries seeking to innovate and enhance efficiency. However, the journey through our project revealed several critical insights:

9.1.1 Web3 Faces Significant Barriers for Industry Adoption

These barriers are classified into four main categories: internal organizational activities, relationships with partner organizations, system-related technological hurdles, and additional external barriers. One significant challenge is the cost associated with adopting Web3 technology, particularly due to the dynamic nature of blockchain technology, which undergoes frequent upgrades and procedural changes. Additionally, there is a lack of expertise in Web3 technology, as it represents a significant departure from the development standards of Web 2.0-based applications. This necessitates substantial investment in skill development and IT tools. Furthermore, the human factor introduces the risk of erroneous data being permanently recorded in the blockchain, highlighting the importance of integrating auditors into the process to ensure data integrity.

9.1.2 Success of Web3 Depends on the Maturity of Development Tools

One major hurdle is the continuous evolution of tools and frameworks, exemplified by Ethereum's numerous iterations and transition from Proof-of-Work to Proof-of-Stake consensus mechanisms. Scalability issues, particularly evident in Ethereum due to high gas prices on testnets, pose significant obstacles for supply chain networks. Additionally, the immaturity of Web3 tools in gaming, such as limited SDK support for platforms like Unity, requires further development for comprehensive integration. These challenges underscore the dynamic nature of Web3 development, requiring developers to remain agile and adapt to emerging tools and standards.

9.1.3 General User Perception Remains Negative

As discussed previously, many people have a negative bias towards blockchain technology due to its reliance on cryptocurrency. While we obtained differing opinions regarding Web3 from each of our chosen sectors, the general outlook was negative.

In the gaming industry, the consensus was overtly negative. Testers expressed their distaste for the inconvenience that Web3 brought to the game, as well as their lack of trust in the blockchain and cryptocurrency. They found that despite a few benefits including some improvements to the backend of games, the inconvenience and stigma it brought with it outweighed the positives.

In real estate, the insights from our interview indicate a cautious stance towards the integration of blockchain technology in real estate. While the potential for digital representation of property ownership was acknowledged, our feedback underscores the challenges of disrupting entrenched industry practices. This resistance suggests a broader reluctance within the sector to depart from traditional methodologies, even in the face of technological advancements promising increased efficiency and transparency.

In supply chain management, there was a positive reaction regarding blockchain's ability to help authenticate products with its immutable and transparent aspects. However, an emphasis was placed on blockchain's inability to solve all current issues alone.

9.2 Future Work

As we look towards the future, several areas emerge as pivotal for the continued exploration and integration of Web3 technologies:

9.2.1 Organizational Strategies for Embracing Web3 Technology

To address the significant barriers hindering the adoption of Web3 technology, organizations would need to adopt a comprehensive approach. This involves investing in training and skill development to bridge the expertise gap in blockchain technology. Collaborative partnerships with industry peers and technology providers should be forged to facilitate knowledge sharing and collective problem-solving. Organizations must also prioritize continuous learning and adaptation to stay abreast of the dynamic nature of blockchain advancements. To mitigate risks associated with data integrity and human error, robust risk mitigation strategies should be implemented, including integrating auditing processes and deploying smart contracts with error correction mechanisms. Additionally, conducting a thorough cost-benefit analysis is essential to evaluate the long-term advantages against the initial investment. By implementing these measures, organizations can overcome barriers and position themselves for success in the evolving landscape of Web3 technology adoption.

9.2.2 Prioritizing Development Tools and Collaboration

To ensure the success of Web3, it is crucial to prioritize the refinement and advancement of development tools and frameworks. This entails a concerted effort in resource allocation towards research, development, and ongoing enhancement of these tools. Collaboration and community engagement among developers, researchers, and industry stakeholders are essential for sharing knowledge, identifying common challenges, and collectively innovating solutions. Priority should be given to addressing scalability issues, particularly in platforms like Ethereum, through the development of efficient scaling solutions. Additionally, fostering closer partnerships with technology providers such as Unity in the gaming sector to improve SDK support will facilitate seamless integration of Web3 functionalities. By focusing on these areas, stakeholders can overcome existing challenges and unlock the full potential of Web3, driving innovation and broader adoption.

9.2.3 Overcoming Negative Perceptions and Fostering Blockchain Adoption

To navigate the persistently negative user perception of blockchain technology, it is imperative to proceed with caution and address the concerns highlighted across different sectors. Key recommendations include launching educational campaigns to broaden understanding beyond cryptocurrency, prioritizing user experience in design, conducting pilot programs to demonstrate practical benefits, ensuring regulatory compliance, fostering collaborations to leverage expertise, advocating for incremental adoption, and establishing feedback mechanisms for continuous improvement. By implementing these strategies, stakeholders can work towards mitigating skepticism and facilitating the adoption of blockchain solutions across diverse industries.

References & Appendices

Barley, J. (2024). Beginner's Guide to Smart Contracts: Everything You Need to Know. CoinBureau. Retrieved online from https://www.coinbureau.com/education/ethereum-smart-contracts/

Bashir, D. (2022, August 19). Axie Infinity leaves Filipino players penniless and defeated. IGN Southeast Asia. Retrieved online from https://sea.ign.com/axie-infinity/189292/news/axie-infinity-leaves-filipino-players-penniless-and-defeated

Benabdallah, A., Audras, A., Coudert, L., El Madhoun, N., & Badra, M. (2022). Analysis of Blockchain Solutions for e-voting: A systematic literature review. IEEE Access, 10, 70746–70759. https://doi.org/10.1109/access.2022.3187688

CBP. (2024). Intellectual Property Rights. CBP.gov. Retrieved online from https://www.cbp.gov/trade/priority-issues/ipr

Davis, M. (2023, September 13). ERC-721 vs ERC-1155 - The Clash of Titans. Doubloin. Retrieved online from https://www.doubloin.com/learn/erc-271-vs-erc-1155

Dealessandri, M. (2023, November 23). *What is the best game engine: is Unity right for you?* GamesIndustry.Biz. Retrieved online from https://www.gamesindustry.biz/what-is-the-best-game-engine-is-unity-the-right-game-engine-for-you

DeHealth. (2024). Company. DeHealth. Retrieved online from https://www.dehealth.world/about/company

Deloitte. (n.d.). Blockchain in commercial real estate. Retrieved online from https://www2.deloitte.com/us/en/pages/financial-services/articles/blockchain-in-commercial-real-estate.html

Dewey, J. N., Patel, S. (2024). Blockchain & Cryptocurrency Laws and Regulations 2024 | USA. Global Legal Insights. Retrieved online from https://www.globallegalinsights.com/practice-areas/blockchain-laws-and-regulations/usa#chaptercontent2

Emergence in Code Plugins - UE Marketplace. (2023, February 13). Unreal Engine. Retrieved online from https://www.unrealengine.com/marketplace/en-US/product/emergence

Emergence SDK | Infrastructure | Unity Asset Store. (2023, November 13). Retrieved online from https://assetstore.unity.com/packages/decentralization/infrastructure/emergence-sdk-252187

EVM Codes. (n.d.). An Ethereum Virtual Machine Opcodes Interactive. Retrieved online from https://www.evm.codes/?fork=shanghai

Fontana, R., Girod, S.J.G., Kralik, M. How Luxury Brands Can Beat Counterfeiters. Harvard Business Review. Retrieved online from https://hbr.org/2019/05/how-luxury-brands-can-beat-counterfeiters

Frankenfield, J. (2022). Gas (Ethereum): How Gas Fees Work on the Ethereum Blockchain. Investopedia. Retrieved online from https://www.investopedia.com/terms/g/gas-ethereum.asp

Frankenfield, J. (2023). Cryptocurrency Wallet: What It Is, How It Works, Types, Security. Investopedia. Retrieved online from https://www.investopedia.com/terms/b/bitcoin-wallet.asp

Garnett, A. J. (2024). Ethereum gas fees: The cost of doing (crypto) business. Britannica. Retrieved online from https://www.britannica.com/money/ethereum-gas-fees-eth

Georgiades, A. (2023). Web3 Is Becoming More Popular: Where's The Regulation? Forbes. Retrieved online from https://www.forbes.com/sites/forbesfinancecouncil/2023/06/26/web3-is-becoming-more-popular-wheres-the-regulation/?sh=6555f26cc358

GitHub. (2022). Goerli (Goerlitzer Testnet). GitHub. Retrieved online from https://github.com/eth-clients/goerli

Grishin, D., Obbad, K., Estep, P., Quinn, K., Wait Zaranek, S., Wait Zaranek, A., Vandewege, W., Clegg, T., César, N., Cifric, M., & Church, G. (2018). Accelerating Genomic Data Generation and Facilitating Genomic Data Access Using Decentralization, Privacy-Preserving Technologies and Equitable Compensation. Blockchain in Healthcare Today. Retrieved online from https://doi.org/10.30953/bhty.v1.34

Grishin, D., Raisaro, J. L., Troncoso-Pastoriza, J. R., Obbad, K., Quinn, K., Misbach, M., Gollhardt, J., Sa, J., Fellay, J., Church, G. M., & Hubaux, J.-P. (2019). Citizen-Centered, Auditable, and Privacy-Preserving Population Genomics. bioRxiv. Retrieved online from https://doi.org/10.1101/799999

Hamid, J. (2024, February 27). Ethereum's Dencun Upgrade Officially Activated On All Testnets. Cryptopolitan. Retrieved online from https://www.cryptopolitan.com/ethereum-dencun-upgrade-officially-activated/

Hendler, J. (2009). Web 3.0 Emerging. Computer, 42(1), 111-113. https://doi.org/10.1109/MC.2009.30

IBM. (2024). What are smart contracts on blockchain? IBM. Retrieved online from https://www.ibm.com/topics/smart-contracts

Infura | Infrastructure | Unity Asset Store. (2023, February 23). Unity Asset Store. Retrieved online from https://assetstore.unity.com/packages/decentralization/infrastructure/infura-247106

Inventory Service. (n.d.). Emergence Documentation. Retrieved online, from https://docs.emergence.site/features-overview/inventory-service

IPFS. (n.d.). Persistence, permanence, and pinning. IPFS Docs. Retrieved online from https://docs.ipfs.tech/concepts/persistence/

Jasperse, J. (2022). 50-State Review of Cryptocurrency and Blockchain Regulation. The Wharton School of the University of Pennsylvania. Retrieved from online https://stevenscenter.wharton.upenn.edu/publications-50-state-review/

Kim, C. (2020). Ethereum 2.0: How it Works and Why it Matters. Coindesk. Retrieved online from https://theblockchaintest.com/uploads/resources/file-844047896485.pdf

Koenig, T. (2023). How Much Does An IPFS Pinning Service Cost? Pinata. Retrieved online from https://www.pinata.cloud/blog/how-much-does-an-ipfs-pinning-service-cost

Lambert, D. M., and M. G. Enz. 2017. "Issues in Supply Chain Management: Progress and Potential." *Industrial Marketing Management 62 (Supplement C): 1–16*. Retrieved online from doi:10.1016/j.indmarman.2016.12.002

Laurenson, J. (2005). France awash with fashion fakes. BBC News. Retrieved online from http://news.bbc.co.uk/2/hi/europe/4378537.stm

Martynov, O. (2020). *Sustainability Analysis of Cryptocurrencies Based on Projected Return on Investment and Environmental Impact* (Order No. 28275645). Available from ProQuest One Academic. (2480284875). http://ezproxy.wpi.edu/login?url=https://www.proquest.com/dissertations-theses/sustainability-analysis-cryptocurrencies-based-on/docview/2480284875/se-2

Moralis. (2023). Ethereum Testnet – Full Ethereum Test Network Guide. Moralis. Retrieved online from https://moralis.io/ethereum-testnet-full-ethereum-test-network-guide/

Morton, H. (2022). Blockchain 2022 Legislation. National Conference of State Legislatures. Retrieved online from https://www.ncsl.org/financial-services/blockchain-2022-legislation

Nebula (2024). Technology at Nebula Genomics. Nebula Genomics. Retrieved online from https://nebula.org/technology/

Neobrix (2024). Coinbrix - Demo - App. GitHub. https://github.com/coinbrix/demo-app

Nevil, S. (2023). What Is Proof of Work (PoW) in Blockchain? *Investopedia*. Retrieved online from https://www.investopedia.com/terms/p/proof-work.asp

NFT Checkout. (n.d.). Singularity Developer Documentation.Retrieved online, from https://docs.s9y.xyz/payments-integration-guide/nft-checkout

NHGRI. (2023). DNA Sequencing Costs: Data. NHGRI. Retrieved online from https://www.genome.gov/about-genomics/fact-sheets/DNA-Sequencing-Costs-Data

OECD/EUIPO. (2021). Global Trade in Fakes: A Worrying Threat. Illicit Trade, OECD Publishing. Retrieved online from https://doi.org/10.1787/74c81154-en

Reiff, N. (2023, November 15). *The Collapse of FTX: What Went Wrong With the Crypto Exchange?* Investopedia. Retrieved online from https://www.investopedia.com/what-went-wrong-with-ftx-6828447

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. International journal of production research, 57(7), 2117-2135. Retrieved online from https://www.tandfonline.com/doi/full/10.1080/00207543.2018.1533261

Sarkis, J., and Q. Zhu. 2018. “Environmental Sustainability and Production: Taking the Road Less Travelled.” *International Journal of Production Research*. Retrieved online from 56 (1–2): 743–759.

Secure decentralized application development. Follow My Vote. (2023). *Follow My Vote*. Retrieved online from https://followmyvote.com/

Singularity - web3 made easy in Code Plugins - UE Marketplace. (2023, June 8). Unreal Engine. Retrieved online from https://www.unrealengine.com/marketplace/en-US/product/singularity-web3-made-easy

Substack. (n.d.). Homepage. *The Lunacian*. Retrieved online from https://blog.axieinfinity.com/

Szabo, N. (1996). Smart contracts: building blocks for digital markets. EXTROPY: The Journal of Transhumanist Thought,(16), 18(2), 28.

Tsegaye, M. (2023). Alchemy Decentralized Supply Chain. GitHub. Retrieved online from https://github.com/sciemesfin/alchemy-decentalized-supply-chain

Tut, K. (2023). Is IPFS A Blockchain? Pinata. Retrieved online from https://www.pinata.cloud/blog/is-ipfs-a-blockchain

Unity Real-Time Development Platform | 3D, 2D, VR & AR Engine. (n.d.). Unity. Retrieved online from https://unity.com

Unreal Engine | The most powerful real-time 3D creation tool. (n.d.). Unreal Engine. Retrieved online from https://www.unrealengine.com/en-US

US News. (n.d.). These Countries Have the Cheapest Manufacturing Costs. US News. Retrieved online from https://www.usnews.com/news/best-countries/rankings/cheap-manufacturing-costs

Wang, A.X. (2023). Inside the Delirious Rise of 'Superfake' Handbags. The New York Times Magazine. Retrieved online from https://www.nytimes.com/2023/05/04/magazine/celine-chanel-gucci-superfake-handbags.html

Wang, Q., Li, R., Wang, Q., & Chen, S. (2021). Non-Fungible Token (NFT): Overview, Evaluation, Opportunities and Challenges. arXiv preprint arXiv:2105.07447.

Ward, J. (2008). WHAT IS A GAME ENGINE? -- An Introduction to a Cornerstone of Modern Game Development. Game Developer, Suppl.Game Career Guide, , 27-n/a. Retrieved online from http://ezproxy.wpi.edu/login?url=https://www.proquest.com/trade-journals/what-is-game-engine-introduction-cornerstone/docview/219098107/se-2

Werkheiser, B. (2022). A Complete Guide to Ethereum's Rinkeby Testnet. *Alchemy*. Retrieved online from https://www.alchemy.com/overviews/rinkeby-testnet

Werkheiser, B. (2022). What is an application-specific blockchain (appchain)? *Alchemy*. Retrieved online from https://www.alchemy.com/overviews/what-is-an-appchain

Woods, G. (2024). Ethereum: A SECURE DECENTRALISED GENERALISED TRANSACTION LEDGER. GitHub. Retrieved online from https://ethereum.github.io/yellowpaper/paper.pdf

WTO. (2019). World Trade Statistical Review 2019. World Trade Organization. Retrieved online from https://www.wto.org/english/res_e/statis_e/wts2019_e/wts19_toc_e.htm

YCharts. (n.d.). Ethereum Average Gas Price. YCharts. Retrieved online from https://ycharts.com/indicators/ethereum_average_gas_price

Zhang, R., Xue, R., & Liu, L. (2019). Security and Privacy on Blockchain. ACM Computing Surveys, 52(3), Article 51. Retrieved online from https://doi.org/10.1145/3316481

Zheng, Z., Xie, S., Dai, H., Chen, X., & Wang, H. (2017). An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends. In 2017 IEEE International Congress on Big Data (BigData Congress) (pp. 557-564). Retrieved online from https://doi.org/10.1109/BigDataCongress.2017.85