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Minor Dissertation In Financial Technology

A Model For Collaborative Creation And Ownership Of Digital Products

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DECLARATION

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Abstract

This thesis presents Axone, a system that enables decentralized collaborative creation of digital products through interconnected digital content blocks. Axone provides the provenance of a digital product by storing its history since creation in an immutable Directed Acyclic Graph (DAG) data structure. This history comprises digital content blocks used in its creation, including how they referenced each other in the development of the final digital product. Through referencing, credit attribution is achieved and royalty fees due to the referenced content block are recorded and enforced. Content creators can concurrently work on a succeeding content block to produce various versions of unique digital products from the same original content block. Axone focuses on written work enabling different authors to contribute to a book (the digital product) in the form of chapters (digital content blocks), until its completion. Axone uses blockchain technology and web monetization to provide provenance for each chapter and to stream payments to authors.

Keywords: digital product, digital content, digital content block, digital asset, provenance, derivative work, direct acyclic graph.

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1 Introduction

Ownership of digital content must afford the owner rights to revenue and control of future use of their content by other parties. The internet allows content creators to share their content to a large audience of people. This content can be protected by copyright laws against reproduction and derivative works, although the latter can be done under the fair use doctrine [Guzman, 2015].[1] The conditions for which derivative works can be created under fair use are very broad, which results in many of these works being taken down from platforms such as YouTube and other popular digital content-sharing sites [Guzman, 2015]. It is therefore beneficial for derivative works to reference the originating content to enable transparent collaborations and credit attribution.

Theodor Holm Nelson (Ted Nelson) is the pioneer of the concept of *hypertext*. The initial vision for hypertext was a system of modular paragraphs that are separate but linked together in a tree like structure. The different links would offer different branches of consuming content which he termed *the thousand theories program*[Barnet and Moulthrop, 2012]. The system would record all human literature with all its historical versions, including the interconnections of the paragraphs whilst acknowledging authorship, ownership and linkage. The idea of hypertext is not only constrained to text but to media as well - and thus can be termed *hypermedia*. What is now known as the World Wide Web (web) uses the hypertext concept - with hyperlinks or Uniform Resource Locators (URLs) linking not only text but other types of media. While the web provides a way to publish and reference pre-existing content through hyperlinks, it does not preserve the history of the digital content of the web pages nor does it afford the rights of ownership to the

[1] A 'derivative work' is a work based upon one or more pre-existing works, in which a work may be recast, transformed or adapted [Guzman, 2015]

content creators.

This thesis first defines ownership and examines the entitlements of ownership.[2] After having a clear understanding of the rights of ownership - the rest of the thesis aims to design a solution for ownership of digital content. An owner is entitled to control, use, encumber, alienate and to vindicate. The entitlement to control gives an owner the powers of exclusion over the owned object. The entitlement to use gives the owner exclusive rights of obtaining income through the object owned. The entitlement to encumber gives the owner rights to grant access of the object to another entity for use. The entitlement to alienate gives the owner the rights to transfer ownership of the object to another entity. The entitlement to vindicate allows the owner to claim the object owned back from another entity. This thesis proposes Axone - a system designed to avail these rights to the owners of digital content on the web.

For Axone to meet the desired requirements there were some important factors to consider in the design. The first consideration was decentralization. As discussed in section 2, centralized digital platforms have problems which lead to limited ownership rights of content creators. The second consideration was security. For owners to have exclusive control of an object, security is important to prevent unauthorized access. The third consideration was immutability. Disputes over ownership may arise as a result of falsified or missing records. An immutable database can provide history of an object and thus prove ownership and settle any disputes. These design choices are fulfilled by blockchain technology which is discussed in detail in section 3.

Axone solves the issue of ownership through asymmetric cryptography, referencing and credit attribution of digital content. Using asymmetric cryptography, a user can

[2] These are the legal rights an owner of an object has.

control who can view or use their content through a Private Key which is known only to that user. A record of each digital content block and the blocks referencing it, are kept in an immutable decentralized database. These records are kept in a Directed Acyclic Graph (DAG) data structure on a database with blockchain features. A DAG cannot have referencing cycles, which ensures that each reference path has a termination content block. The termination of a path creates a digital product which consists of all the digital content blocks in that path. To achieve credit attribution, a reference between two content blocks in the DAG contains data representing the royalty as a percentage that will be paid by the referencing content block.[3] The technical details of the implementation are in sections 4.3 and 4.4.

The ownership of each content block can be transferred to another if an agreement between the two parties is reached off the platform.[4] This transfers ownership and royalty rights to the new owner. Each content block can be represented as an NFT on a chosen blockchain.[5] These can be auctioned on various NFT marketplaces by the owner of the block. OpenSea is an example of an NFT marketplace which facilitates the auctioning and transfer of NFTs to the highest bidder. Section 4.6 covers considerations for future work which looks at transfers as well as some limitations of Axone. Finally section 5 concludes this thesis.

[3]This data will be in the form of a payment pointer to both blocks split in an agreed proportion.

[4]On Axone each content block is a chapter of a book.

[5]NFT stands for Non Fungible Token. It is a unique piece of digital data that cannot be interchanged for another NFT of the same type.

2 Digital content on the internet

The third industrial revolution (TIR) of the 1980s and 1990s was mainly characterised by the personal computer (PC) [Barnatt, 2001]. This removed barriers that prohibited the broader community from creating and publishing their own digital content.[6] For instance, expensive equipment was required to create an analogue video. This changed when camcorders were made available in the market so that users could create homemade videos [Reyna et al., 2018]. With the move from magnetic tapes to memory cards and internal storage in the 1990s, the content on the camcorder could be easily transferred to a PC using a USB interface, and users could edit the videos before publishing to the internet. In the late 1990s, the internet became widespread with various websites going online [Cohen-Almagor, 2011]. This led to the creation of platforms for viewing and sharing digital content such as YouTube. [7] New challenges for content creators were born out of these technological advancements. The content created could now be easily copied and reproduced by another party without the permission of the content creator. [8] Creators depend on the platforms to upload their content, to control access, and for preventing unauthorized reproduction of their digital content [Mahesh and Mittal, 2009].

[6] Typically, digital content refers to information available for download or distribution on electronic media such as an ebook or iTunes song, but many in the content industry argue that digital content is anything that can be published.

[7] In August 2020, more than 500 hours of video were uploaded to YouTube every minute [Statista, 2021b]

[8] 'Content creator' and 'owner' will be used interchangeably in this report. An owner is generalised to an object and a content creator to digital content

2.1 Ownership of content on digital platforms

It is important to understand the term ownership and it's implications before attempting to create a solution for it in the digital space. In South African case law, ownership is defined as:

> *The most complete real right that a legal subject can have regarding an object, or as the real right which gives the owner the most complete and absolute entitlements to an object*[Boshoff, 2013].

The legal owner of an object is entitled to the proceeds from its use. Thus, the use of an object should be the privilege of the owner and any unauthorised use must be restricted by law and any other means necessary. [Honoré, 1961] lists eleven rights an entity has over an object they own. The summarised entitlements to the owner are:

- Entitlement to control which allows the owner to physically control and keep an object.
- Entitlement to use allows the owner to benefit from the use of an object.
- Entitlement to encumber is the entitlement to grant limited real rights to others in respect of the object.
- Entitlement to alienate entitles the owner to transfer the object to someone else.
- Entitlement to vindicate allows the owner to claim the object from someone else.

This definition of ownership and the entitlements thereof can easily be applied to physical objects – both in theory and in practice. In theory they can also be applied to digital objects, but in practice this is not as straightforward to implement. For instance, the entitlement to control can be implemented using a lock and key on a physical property but for digital content such an implementation might be inefficient and in some cases impossible. It is important to understand how existing platforms have tried to address the issue of digital content ownership in order to safeguard the interests of content creators.

It is equally important to understand the role of digital platforms in the current digital market. Digital platforms emerged as a result of the TIR for bringing together producers and consumers [Fredriksson et al., 2019]. This is essential for reducing information asymmetries as the search costs for consumers decreases [Jiaqi et al., 2015]. Instead of purchasing an item at an inflated price, users could now compare from multiple producers and purchase an item at the cheapest price. These platforms can be referred to as *transaction platforms*. They support the exchange of goods and services between the two parties, producers and consumers, in a two-sided market. There are also *innovation platforms* where content creators can create any form of digital products – for example, software, games, videos, music or e-books – used by consumers for entertainment, productivity or educational purposes [Fredriksson et al., 2019]. Whatever the platform type, they act as intermediaries between the two parties to facilitate the exchange of goods. To provide the best experience, digital platforms capture data about consumer preferences in relation to their demographics and behaviours on the platform. It is now apparent that the competitiveness of digital platforms depends on this data [Cremer et al., 2019].

2.1.1 Entitlement to use

Entitlement to use is essential for ownership. This means that the owner is entitled to the proceeds from the use of an object, which they can control and disburse as they please. As a result of the business models adopted by digital platforms this is not usually the case. The two main business models are *advertising* and *subscription* based models which will be discussed in the following section. The advertising business model relies on the processing of consumer data that is sold to businesses in the form of targeted advertisements. Of note is that only after the data is processed and information is retrieved from the data does its value become apparent. The information retrieved can be used for targeted advertising and to provide insights into businesses and other organisations that may require this information to make data-driven decisions [Fredriksson et al., 2019]. Due to this process of information retrieval using Machine Learning (ML) and Artificial Intelligence (AL), the value of data can only be ascertained after processing. The data producer cannot negotiate for a fair price since the value created comes after processing. At this stage, the value is known only by the owners of the digital platform. In a capitalist economy, parties will act in their best interests unless prompted otherwise by regulations. Thus, data producers have little bargaining power and usually get a disproportionate amount of the value created [Fredriksson et al., 2019]. This same effect is realized by content creators. Digital platforms determine at what stage the value of content is realized. At this point, the content creators no longer have control of the value created by their content. Thus digital platforms limit the entitlement to use, which is a necessary condition for ownership.

2.1.2 Entitlements to control and encumber

Entitlement to control is another essential right for ownership. This is closely related to entitlement to encumber. Both relate to the control the owner has over an object, such that they can restrict access to it and give rights of access to any party they choose. For digital content this is achieved through copyright laws. In the United States of America (USA), the Online Copyright Infringement Liability Limitation Act (OCILLA) was created to enforce platforms to promptly remove any content that infringes copyright laws [Guzman, 2015]. This content can clearly infringe copyright laws, but some of it is derivative content such as commentaries, criticisms or parodies, which is considered fair use and is thus protected under the fair use legal doctrine. The owner of the content though, needs only to report any of these works as used without authorization and under OCILLA they are usually taken down. It can be argued that Laws such as OCILLA and the Digital Economy Act (DEA) of the UK stifle innovation since other people with different ideas cannot create derivative content from existing content [McConaghy et al., 2017].

[McConaghy et al., 2017] argue that if there is a way for creators to pay for creating derivative content from existing content, they would do it. This would mean that every piece of digital content would have metadata about the creator and all its history, such that another creator will know about the revisions it has gone through, so as to have a full picture before commenting, criticising or adding to the content. Such an innovation would lead to better control of digital content for creators. They could decide pre-publication on the royalties required for a derivative work or better still the market demand could be an indicator of the value added through the derivative content. Thus, rather than having little to no control of derivative works, the owner could control the conditions under which derivative works are created from their content.

2.1.3 Entitlements to alienate and vindicate

On a digital platform the entitlement to alienate gives the owner the rights and possibility to transfer their content to another. This is closely related to entitlement to vindicate, which gives an owner the right to claim their content from another entity. To achieve both, the content owner needs to provide irrefutable proof of its ownership, which is also known as vindication. With physical property, for example, this can be done through a central registry (title by registry). The legal owner must have a public deed which is held by an official national registry [Garcia Teruel and Simon-Moreno, 2021]. In the case of digital content in the United States of America (USA), copyright laws automatically apply to digital content on creation. However, it is not recorded who owns the copyrights until the owner registers their work with the Copyright Office. Registration has the advantage that the owner can litigate to enforce exclusive rights of use for the content [United States Copyright Office, 2021]. Without registration, the platform decides whether or not to remove content that the owner has identified as breaking copyright laws.

A central registry suffers from the issues of centralized systems such as a single point of failure and the concentration of authority [Hasan and Salah, 2018]. Most registries are now digital databases which are prone to cyber attacks which can have disastrous consequences in terms of resolving ownership disputes. The centralized structure for vindication also restricts the fractional ownership of assets. For instance, with real estate the market is less liquid in comparison to the market for equities for example, and it is difficult to diversify in this market because of the amount of capital required to invest in a single unit of an asset [Baum, 2020]. In order to make real estate more liquid, fractional ownership is crucial.[9] The practical implications of this with the current centralized registries is costly as the volume of ownership records substantially increases with each owner having to process proof of ownership with the central registry [Baum, 2020]. Thus, even though centralized registries provide a service to entitle owners to alienate and vindicate, they are more prone to attacks and will not scale for fractional ownership.

[9] Investopedia defines fractional ownership as a form of collaborative consumption where the overall cost of a property is split among a group of owners or users.

2.2 Monetization of content on digital platforms

As previously discussed, an owner is entitled to the proceeds from the use an object. However, with the emergence of Big Tech companies this has not been the case.[10] The Big Tech companies have developed most of the platforms in use from entertainment, utility, e-commerce and a myriad of subcategories of these [Fernandez et al., 2020].[11] A report in 2020 by the House Committee Judiciary concluded that the four biggest tech giants – Amazon, Facebook, Apple and Google – have engaged in a range of anti-competitive behaviour:

> *To put it simply, companies that once were scrappy, underdog startups that challenged the status quo have become the kinds of monopolies we last saw in the era of oil barons and railroad tycoons*[Nadler and Cicilline, 2020].

The monopoly power of the Big Tech companies is sustained through the network effects they have created.[12] This makes it difficult for users, producers and consumers to leave these platforms – even if other platforms offers better services. The main source of revenue for digital platforms is advertising and rent [Fernandez et al., 2020].[13] Rent can be charged directly for every transaction between the producer and the consumer, as is done in the subscription model. It can also be withheld from the producers in the advertising model. It is important to understand these two models and how they affect content creators.

[10] Big Tech are the dominant information technology companies in terms of consumer base and market capitalization.

[11] E-commerce is the buying and selling of products over the internet.

[12] Network effects are a phenomenon where the utility derived from the use of a service or platform increases with the number of users that use it.

[13] Rent is a tax imposed on the users of a platform for using its services.

2.2.1 Advertising model

Advertising is the primary source of revenue for most social media platforms [Buhler et al., 2015].[14] In the second quarter of 2021, the advertising revenue (ad revenue) for Facebook was USD28.5 billion compared to USD497 million from other revenue streams. This means that 98 per cent of the total revenue is from advertising [Statista, 2021a]. This business model works because the product offered to users, digital content, is provided for free at face value. The cost however, is the data that users give to these digital platforms – such as preferences, age, race and personal behaviour [Fredriksson et al., 2019]. Once this data is processed it can provide business intelligence to companies that in turn create targeted advertising on these digital platforms. Thus the value of the data is only known after processing and is in the control of the platforms such that they have the bargaining power over the producers and consumers [Fredriksson et al., 2019].

As the only source of revenue on most social media platforms is indirect in the form of advertisements, it forces content creators to target their content to a wide range of users through the categories they select for their content. By doing so, their content is exposed to a larger audience which increases the chance of being viewed and hence increased ad-revenues [Shapiro and Aneja, 2018]. A loyal audience is usually willing to pay more than the ad-revenue for each view of the same content if a way to do so is provided [CB Insights, 2021]. This has seen the emergence of platforms with the subscription business model like Patreon and Only Fans, where the creators get the larger portion of the revenues [CB Insights, 2021].

[14] Social media refers to platforms that allow users to create and consume content on the internet [Lin and Rauschnabel, 2016]

2.2.2 Subscription model

The subscription model is a direct revenue source for content creators. Users who enjoy certain content can follow that specific content creator and pay a periodic subscription such as a monthly fee to view the content [Shapiro and Aneja, 2018]. This enables revenue earnings even with a small number of followers compared to platforms such as YouTube where a creator can only start monetizing their content when they reach a certain number of views and subscribers [Shapiro and Aneja, 2018]. This model is more candid in terms of the revenue split between the creator and the platform. Content creators know what each subscriber pays and how much is charged as fees by the platform. In addition, creators can create exclusive content which can be viewed by premium-level followers that pay more for it. For instance, Twitter is rolling out functionality to allow super followers to pay a subscription for exclusive tweets [CB Insights, 2021]. It is clear that indirect monetization is not sufficient for creators. It deflates the value of their content as there is no mechanism to assess the value of the content to the consumer [CB Insights, 2021]. Direct monetization through subscriptions offers a way to differentiate the audience and hence earn more money from followers that value the content more.

3 A use case for blockchain

Blockchain is a new technology that can be used to provide ownership of digital content, with all its entitlements, to the creator. In the preceding chapters it is apparent that digital platforms that act as intermediaries between the consumers and producers of content have not given full entitlements to content creators. Blockchain offers decentralization, security and traceability – which is a perfect solution for the ownership of digital content.

3.1 The blockchain technology

A blockchain is a decentralized digital ledger that can record transactions between parties such that they are immutable [Yaga et al., 2018].[15] Each transaction must be validated by verifying authorization and the credit balance available to fulfil the transaction. Verification of authorization is achieved through asymmetric cryptography. Validators on the blockchain must agree on the state of the ledger after processing valid transactions and appending them to the ledger. A consensus mechanism should be adopted to achieve this. The most common ones are the Proof of Work (PoW) and Proof of Stake (PoS) consensus protocols [Zheng et al., 2017]. The key characteristics of the blockchain technology that make it an ideal solution for providing ownership of digital content are decentralization, security and auditability [Yaga et al., 2018].

[15] Blockchains have no central repository or central authority.

3.1.1 Decentralization

The primary function of digital content platforms is to act as intermediaries between creators and consumers. As discussed in section 2.2, these digital platforms have more bargaining power than the content creators, which results in the loss of entitlement for the creators to use and control. Because the data for which the digital platforms rely on for revenue generation is centrally controlled, digital platforms often do not provide data portability, which increases switching costs for creators wanting to use other platforms [Jeon et al., 2016]. The decentralization of data through blockchain technology removes data as a barrier to entry – which promotes innovation and better treatment of both creators and consumers.

Blockchains also enable the decentralized processing of transactions. A consumer and producer can directly transact after agreeing on the value of a product such that there are no costs incurred dealing with an intermediary party [Zheng et al., 2017]. This is made possible by trustless intermediation. A trustless system has certain rules of engagement known and agreed to by all parties involved in any transaction on the system. These rules cannot be unilaterally changed and they are enforced by the system; thus there is no need for an intermediary [Klems et al., 2017]. The rules to be implemented should be programmed in the system such that they are self-verifying, self-executing and cannot be tampered with after they are set. These programs are called smart contracts [Mohanta et al., 2018]. In addition to the smart contracts, supporting actors are needed that offer a registry service for producers such that consumers can find them and directly transact with the producer [Klems et al., 2017].

When a consumer on a decentralized system requests a service or product from a producer, a service delivery mechanism is required. The service must distinguish between paid and non-paid consumer requests. [Klems et al., 2017] propose two service delivery mechanisms: a proxy server or a signature library. With a proxy server, the requests are not sent directly to the producer but go through the proxy that will verify whether the consumer request has been paid for [Klems et al., 2017]. A proxy server has the disadvantage that it is a single point of failure and that trust would need to be put in the third party. With a signature library, each consumer and producer will run the library such that they can verify a request and whether it has been paid for, and send a response accordingly. This approach has the issue that the request handling and verification is the responsibility of the producers and consumers [Klems et al., 2017]. This means they should both be available at all times to respond to these requests. In practice this becomes unscalable. A proxy server ,on the other hand, is scalable. Since the blockchain is public, numerous proxy servers can be built on top of it to avoid a single point of failure inherent in centralized platforms.

The last step is the receipt of service after a payment has been verified on a decentralised platform. Issues can however arise when a consumer pays for a service that is unavailable. [Klems et al., 2017] suggest two methods to resolve this issue: using micro-payments or escrows. Using micro-payments, a consumer will pay for short-time slices of a service. This minimizes losses if the service becomes unavailable. The second method is using an escrow. An escrow is an intermediary service that requires a deposit from both parties such that if one party fails to meet their obligations, ,they forfeit that deposit to the other party. This concept can be modified such that the consumer pays into an escrow and the escrow will only pay the producer for the confirmed value of services provided. The escrow method requires careful design and a consistent measure of the value of service provided to the consumer.

3.1.2 Security

Ownership entitles control and restriction of use of an object by the owner. On digital platforms, content creators cede this power to the platform which then controls who can or cannot view the content. For instance, the terms of service for YouTube specify the following:

> *By providing Content to the Service, you grant to YouTube a world-wide, non-exclusive, royalty-free, transferable, sublicensable licence to use that Content (including to reproduce, distribute, modify, display and perform it) for the purpose of operating, promoting, and improving the Service*[YouTube, 2021].

It also specifies the following licence to other users on their platform;

> *You also grant each other user of the Service a worldwide, non-exclusive, royalty-free licence to access your Content through the Service, and to use that Content (including to reproduce, distribute, modify, display, and perform it) only as enabled by a feature of the Service* [YouTube, 2021].

The latter quote implies that derivative works can be created if YouTube decides to add a feature for it. This already happens on TikTok where users can reuse another creators videos by creating a duet . While this is good for creativity and innovation, credit must be attributed to the original creator under the creator's own terms. The security features of the blockchain technology enable that.

Blockchain technology uses asymmetric cryptography (AC) for security and validation. With AC, each user owns a pair of keys called the private and public keys which are mathematically derived and related to each other. The private key is known only to the user and should be kept hidden from the public. The public key can be broadcast on the network to users without compromising on the security of AC, because the private key cannot be derived from the public key [Yaga et al., 2018]. AC can be used to:

- Verify the integrity of a data or transaction while keeping it public.
- Encrypt data such that only the intended recipient can read it.

Verification can be achieved through a digital signature. The owner of the data will encrypt it with their private key and send the encrypted version together with the original version. Since anyone can access the public key, anyone can verify that the owner of the private key signed that data and that it has not been tampered with. Encryption of data can be achieved by encrypting it with the public key of the intended recipient. Only the private key will be able to decrypt it [Yaga et al., 2018]. Using AC content providers can encrypt their data to control access and to digitally sign their content to prove ownership of their content.

3.1.3 Auditability

Ownership gives an owner the privilege to alienate and vindicate. This means an owner can transfer ownership to another entity and whoever has the ownership is able to prove ownership. Taking property, for example, some legal systems require that the title of ownership be kept in a registry. Third parties can get access to these records to verify ownership before engaging in a transaction for the transfer of an asset [Garcia Teruel and Simon-Moreno, 2021]. Most countries do not have electronic systems for buyers to enquire about the title deeds of a property, which can result in buyers being defrauded [Singh and Vardhan, 2019]. For any asset type, a secure, tamper-proof and public registry is required to facilitate the transfer of ownership.

The cryptographic hash chaining of blocks on a blockchain make it tamper-proof. Each block contains the hash digest of the previous block forming a chain from one block to the next [Yaga et al., 2018]. If a malicious user changes a previous block that has been accepted by a majority of honest miners, the user has to add subsequent blocks to make the tampered chain longer than the legitimate chain. To achieve this, the malicious user should have enough computational power to outproduce other miners on the blockchain. This is termed the 51 per cent attack because the attacker would have gained more influence than all the other miners combined – which is an extremely unlikely given the computational or monetary resources required to achieve this.[16] Thus the blockchain will provide a reliable history of a digital asset since creation, including transfers of ownership and updates to the metadata [McConaghy et al., 2017]. Auditability and vindication through digital signing facilitates the transfer of ownership on a blockchain for digital assets.

[16] Computational resources will be required for proof of work while monetary resources are required for proof of stake consensus mechanisms.

3.2 Related Work

As discussed in the introduction, the idea of modular paragraphs linked together with complex interconnections was first proposed by Ted Nelson. This led to the project Xanadu which will be discussed in the following section. Work has also been done in the field of using the blockchain for decentralised validation and publication of digital assets. These will also be discussed in this chapter.

3.2.1 Xanadu

Ted Nelson had a vision of a system that would record all human literature with all its historical versions, including the interconnections of the paragraphs whilst acknowledging authorship, ownership and linkage. He started a project called Xanadu that would enable users to annotate, reuse and extend documents through hyperlinks. Ted Nelson wanted a system that could record the evolution of knowledge without losing the original sources and keep track of all its versions in the form of literature up until its current state [Barnet and Moulthrop, 2012].

The idea of *transclusion* was the first to be implemented in Xanadu. Transclusion is the reuse of a document or a portion of it in another document through a hypertext reference. The second idea Ted Nelson conceived was that of modular paragraphs that are separate but linked together in a tree like structure. He termed this the *thousand theories program* [Barnet and Moulthrop, 2012] and this quickly became *hypertext*. A user could explore different theories by taking different trajectories through the network of information. Both transclusion and hypertext would enable collaboration between authors through reuse and referencing. Xanadu does not focus on the ownership of the digital content created. Using public key cryptography and blockchain technologies, content creators can control and prove ownership of their content thereby protecting their entitlements on Axone.

3.2.2 IPFS-Blockchain book publication

[Nizamuddin et al., 2018] propose a solution that will provide traceability and visibility of digital content posted online in a decentralized manner. Authenticity of the content can be verified by tracing its publication history to the original creator. The history needs to be credible and should maintain integrity throughout its existence on the system. There are three main parties in this system: the author or content creator, the publisher and the reader. The author creates the book and registers it in a smart contract. A publisher requests to publish after agreeing to the terms and conditions with the author. The publisher publishes the content on IPFS and the author manually checks that the work is the original copy given to be published.

[Nizamuddin et al., 2018] use Ethereum as the blockchain for storing the publication metadata.[17] Smart contracts are used to provide the business logic for recording the different versions that the digital content goes through. The cost of storage space on Ethereum is very high and thus the InterPlanetary File System (IPFS) is used to store the content itself, and the content identifier, which is a cryptographic hash of the content, is stored on the Ethereum blockchain. This system provides auditability through the cryptographic hash verification and decentralization through the decentralized IPFS but little control to the author. Transfer of ownership is not provided therefore compromising on the owner's entitlement to alienate. The publishers still act as the middleman and they have a bargaining advantage as they have control of the release to market of the book thus compromising on the owner's entitlement to use.

[17]Ethereum is a decentralised, open source and distributed computing platform that enables the creation of smart contracts and decentralised applications, also known as dapps.

3.2.3 Blockchain internet ownership layer

[McConaghy et al., 2017] also propose a solution that provides ownership, attribution, provenance and trade of digital content. The solution works with BigchainDB, which is a decentralized, immutable and queryable database. BigchainDB uses asym metric cryptography for verification of assets registered on it through digital signatures. Coupled with immutability, BigchainDB provides the history of any asset on it and is traceable to its origin. BigchainDB also provides capabilities for the transfer of digital content registered on it. This provides the entitlement to alienate for content creators.

BigchainDB does not provide any payment features to cater for the consumption of the digital content by another party. For entitlement to use, the content creator should be able to rent out their content and obtain the income. This brings back the issue of monetization of digital content on a decentralized platform – as discussed previously in section 2.2

4 Axone platform

This section presents Axone, a platform for the ownership of collaboratively created digital content in the form of written work. Axone is a decentralized platform that allows authors to publish their written work in a digital form and receive income from readers, as well as royalties from derivative work.[18]

Axone is designed for collaboration between content creators through the extension of pre-existing content from other creators. The platform is designed for the publication of small units of content or content blocks, which can be extended through referencing until a complete digital product is created. A content block can be extended by various content creators such that different branches are created, resulting in unique digital products from the same content block. Of the different types of digital content, Axone focuses on text as a proof of concept.[19] The design can be applied to any other type of digital content.

On Axone, the digital product is a book, the content creator is an author, and the digital content block is a single book chapter. An author can create and publish a single chapter at a time. The chapter can be a continuation of a pre-existing book or it can be the first chapter of a book. In the case that a chapter is extending a pre-existing book, it must reference one or more preceding chapters from that book.

[18]his can be fictional content such as novels or academic work such as textbooks or proofs of mathematical conjectures.

[19]The main types of digital content is video, audio, images and text.

4.1 System overview

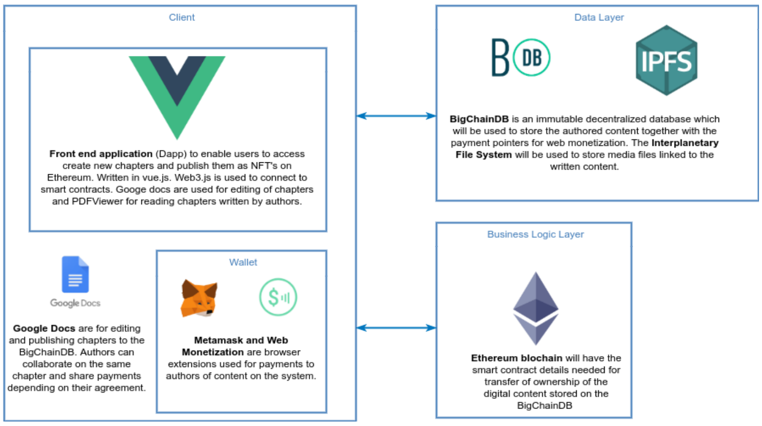

Figure 1: Technology stack overview showing all the interconnected components on Axone. The arrows show the connections between the different components.

The architectural pattern that Axone uses consists of three main logical components: the data logic, the business logic and the user interface (UI).

- The data logic component is for the storage of created content. The stored data is structured to facilitate ease of retrieval. The different fields of the data store the chapter in an encrypted form, the metadata of the chapter , , and the chapter identifiers of any chapters it referenced. The structured data is stored in the BigchainDB – a decentralized and immutable data store. Any media for illustrations of the written work is stored in the Interplanetary File System (IPFS).

- The business logic component contains logic for the encryption and decryption of data from the BigchainDB. It also has logic for the validation of consumer payments before any service delivery.

- The UI component of the system is what the user interacts with. It enables authors to create chapters and reference preceding chapters for extending a book. It also enables readers to access the written work and stream payments to the authors.

Each of these components and how they interact will be examined in the following sections – but first the technologies on which Axone is built are examined.

4.2 Technologies

Before looking at the system components making up Axone, the main technologies used for the platform are discussed. This will give the reader a better understanding of the system and how the components fit together.

4.2.1 BigchainDB

BigchainDB is software that has both blockchain and database properties. The blockchain properties include decentralization, immutability and owner-controlled assets. The database properties include high transaction rate, low latency, indexing and querying of structured data [BigchainDB GmbH, 2018]. These properties enable decentralized platforms for digital asset ownership to be built on top of BigchainDB, without compromising on cost and efficiency.

	Typical Blockchain	Typical Distributed Database	BigchainDB
Decentralization	✓		✓
Byzantine Fault Tolerance	✓		✓
Immutability	✓		✓
Owner-Controlled Assets	✓		✓
High Transaction Rate		✓	✓
Low Latency		✓	✓
Indexing and Querying of Structured Data		✓	✓

Table 1: Blockchain and Database features of BigchainDB. BigchainDB has both sets of features making it efficient for inserting and retrieving as well as immutable.

Table 1 shows a comparison of the features provided by BigchainDB. The cost of storing and retrieving data should be considered when creating a decentralized platform on top of a blockchain. Ethereum is one of the most popular blockchains which implements smart contracts (SC) that are executed by the Ethereum Virtual Machine (EVM).[20] Each node participating in the Ethereum network runs the EVM with a copy of the blockchain. The transfer of value depends on the logic in the SC. The SC have access to data in its storage, which is passed into its functions to execute the logic. The cost of writing data to the SC is high, as a means to keep the distributed database small. In addition to storage costs there are also fees for the execution of logic on the EVM. Processes such as querying for the structured data can end up being expensive [Kostamis et al., 2021]. As a result, platforms built on top of Ethereum resort to other decentralized storage systems such as the IPFS. BigchainDB does not only provide a cheaper decentralized storage, but also one that can execute queries on the data efficiently – which both IPFS and Ethereum do not do.

Database: CRUD	BigchainDB: CRAB
Create	Create
Read	Retrieve
Update	Append
Delete	Burn

Table 2: BigchainDB vs normal Database operations. BigchainDB has no delete or update operations to ensure preservation of historical data.

[20] A smart contract is a program that runs on the Ethereum blockchain, comprising its logic (functions) and data (state)

Databases offering persistent storage have CRUD operations, an acronymn for CREATE, READ, UPDATE and DELETE. To provide immutability, BigchainDB has CRAB operations an acronym for CREATE, RETRIEVE, APPEND and BURN [Jernej, 2017]. Table 2 shows the comparison between a regular database and the BigchainDB. The main differences are the inability to update and delete data to achieve immutability. Instead of updating a record, a new version of the record is appended to the BigchainDB, such that the previous version is still available but the current state of the record is represented by the latest version. It is impossible to delete a record. Instead, an owner can disown a record by transferring it to a specific address with a very low probability of having an owner.

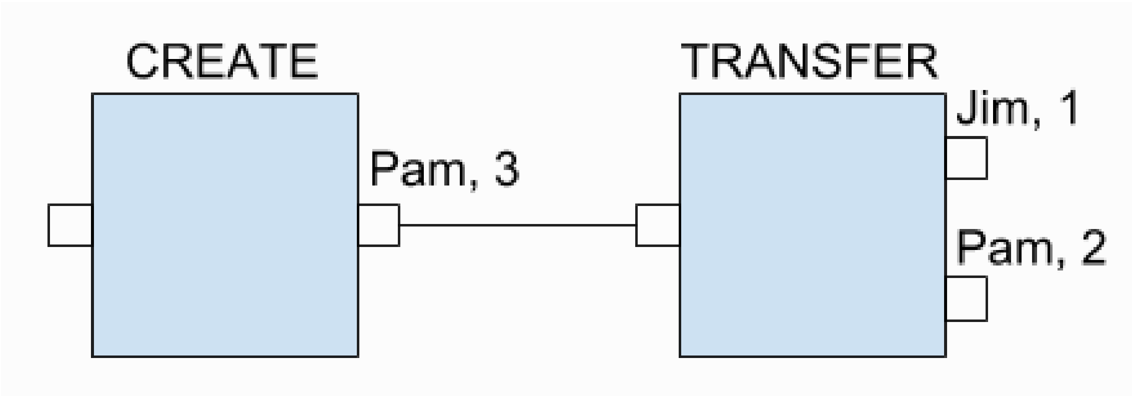

Figure 2: Example BigchainDB transactions. Pam creates an asset with 3 units which results in an output with a value of 3 to be spent. She authorizes a transfer of 1 unit to Jim and the rest she sends back to herself.

The CRAB operations on BigchainDB are facilitated by transactions. Transactions are used to create and transfer the ownership of records.[21] The structure of a transaction is shown below:

[21] A record is a piece of data owned by the public key that signed it. It can represent a digital asset or any other digital object as intended by the creator.

```
{
    "id": id,
    "version": version,
    "inputs": inputs,
    "outputs": outputs,
    "operation": operation,
    "asset": asset,
    "metadata": metadata
}
```

The *id* uniquely identifies the transaction. The *version* specifies the transaction validation rules that are applicable to it. BigchainDB transactions have two types of operations *CREATE* and *TRANSFER*. All the CRAB operations are done using these operations. The *asset* field contains the immutable digital data of the represented object - whether physical or digital. The metadata field allows additional information about the asset field data. In contrast to the asset field, the metadata can be updated with each transaction. A transaction can have multiple inputs and outputs, with the exception of the create transaction which can only have one input. Each output has a condition that is associated to a public key, such that the owner of its private key has control over the expenditure of that output.[22] The inputs of a transaction must meet the conditions specified in the output that it is trying to spend. The most basic condition is the ED25519-SHA-256 condition type, which is represented as below in the transaction. To spend an output having this specific condition, the transfer transaction must be signed with a private key corresponding to the public key in that output condition.

[22] An output can be associated with multiple public keys to create complex conditions for the authorisation of expending it.

```
{
    "type": "ed25519-sha-256",
    "public_key": "HFp773FH21sPFrn4y8wX3Ddrkzhqy4La4cQLfePT2vz7"
}
```

From figure 2, the condition would be in the output *Pam, 3* for instance. Pam is required to fulfill the condition in the output, which requires a private signature corresponding to the public key, in order to use the output as an input to the *TRANSFER* transaction. If the condition is met, the output *Pam, 3* is spent (and therefore cannot be reused) in the transaction and it produces 2 outputs *Jim, 1* and *Pam, 2*. *Pam, 2* will have the same condition - i.e. Pam transferred a portion of the output back to herself and the rest to Jim.

4.2.2 Web Monetization

Web Monetization (WM) is a JavaScript web browser API that allows direct streaming of micropayments to the creator, from a consumer of online content. WM uses the interledger protocol (ILP) to enable the streaming of micropayments using blockchain technology. WM is intended for very small payments, which is recommended as a way to solve the unavailability of service for decentralized services, as discussed in section 3.1.1.

The primary actors in the WM ecosystem are creators, consumers, web monetization receiver (WMR) and web monetization provider (WMP). A creator creates an account with a WMR such that they can receive payments. A consumer creates an account with a WMP such that they can pay for the content they consume – to the creator. The WMP and WMR execute the micro payment transactions on behalf of the consumer and creator using the ILP [Web Monetization, 2021b]. Figure 14 shows the flow of information between the actors in a WM transaction. Detailed information of the flow chart is shown in appendix B. A creator is given a payment pointer by the WMR they sign up with.[23] The payment pointer can be put on a web page with the creator's content using an HTML meta tag. A web browser extension from the WMP is able to resolve the endpoint of the payment pointer and use this information to initiate payments from the users wallet account on the WMP to the WMR.

Collaboration on content creation requires a way to share revenues created from it. WM accomplishes this through a probabilistic revenue-sharing method known as revshare [Web Monetization, 2021a]. Revshare works by randomly choosing from a list of predefined payment pointers based on weights set for the percentage frequency of selection over time. In the code example below, alice has a weight of 50 out of a possible 100. The function *pickPointer* will randomly select alice's pointer 50 per cent of the time. It is important to note that the distribution of revenue will align to the set percentages over time as users visit the webpage.

[23] A payment pointer is an easy to remember identifier of a users account that is safe to share with third parties.

```
const pointers = {
  '$alice.example': 50,
  '$bob.example': 40,
  '$connie.example': 9.5,
  '$dave.example': 0.5
}

function pickPointer () {
    const sum = Object.values(pointers).reduce((sum, weight) => sum + weight, 0)
    let choice = Math.random() * sum

    for (const pointer in pointers) {
        const weight = pointers[pointer]
        if ((choice -= weight) <= 0) {
          return pointer
        }
    }
}
```

4.2.3 Inter planetary file system

IPFS is a peer-to-peer distributed file system with no single point of failure that allows sharing of files through a content identifier (CID). A CID is a unique identifier or fingerprint that is given to the content when it is uploaded onto IPFS. Each node that participates on the network can provide a distributed file that is being requested by another node. This happens when the nodes have this content in their cache as a result of users previously viewing or downloading that content.

4.3 Data logic

Axone is a platform designed for collaboration between authors in the creation of written work. Authors are the content creators and a completed piece of work is the digital product. Collaboration is through the extension of preceding chapters of a piece of writing until its completion. On Axone, contribution can only be done by publishing a single chapter either to begin a new written work or to extend an existing one. A reference to a preceding chapter is created when extending existing work. The chapters are stored on BigchainDB in a directed acyclic graph (DAG) data structure.

A graph is a pair $G = (V, E)$ where V is a set of nodes and E is a set of paired vertices called edges. G is a directed graph when all the edges are ordered. An edge (u, v) in a directed graph is pointing from node u to node v. A DAG is a directed graph with no cycles thus the term acyclic. A directed graph is a DAG only if a *topological ordering* of the graph can be found. A topological ordering is a linear ordering of the graph's vertices such that for every edge (u, v) connecting the nodes, the node u comes before the node v - i.e. a total order $v_1 > v_2 > ... > v_n$ of its nodes such that for any edge $v_i \rightarrow v_j$ we have $i < j$.

On Axone each node is a chapter c_i where i is the chapter number. An edge (i, j) is created when chapter i references chapter j. For topological ordering to be maintained a restriction is enforced on the system such that c_j can only be created if $i < j$. A DAG graph ensures that every path in the graph has a termination node. This is a needed feature to ensure the completion of a digital product. Each chapter is encrypted and stored on BigchainDB through a create transaction - as shown in section 4.2.1. The process of encryption and decryption will be examined in the following section.

Figure 3 is an illustration of a DAG created on Axone. The first node will, by default, be versioned 1.0. The diagram shows two branches created from the root node. The blue nodes are chapters in each branch and the yellow nodes are temporary splits from each branch created after the formation of the blue nodes. These can be chapters giving more context or a background to the chapters on the main branch. Each edge (c_i, c_j) (edge pointing from chapter i to chapter j) is such that $i < j$ which ensures a topological order on the graph. The edge $(c_{2.5}, c_{2.0})$ for instance, is shown in red in figure 3 because $2.5 \nless 2.0$.

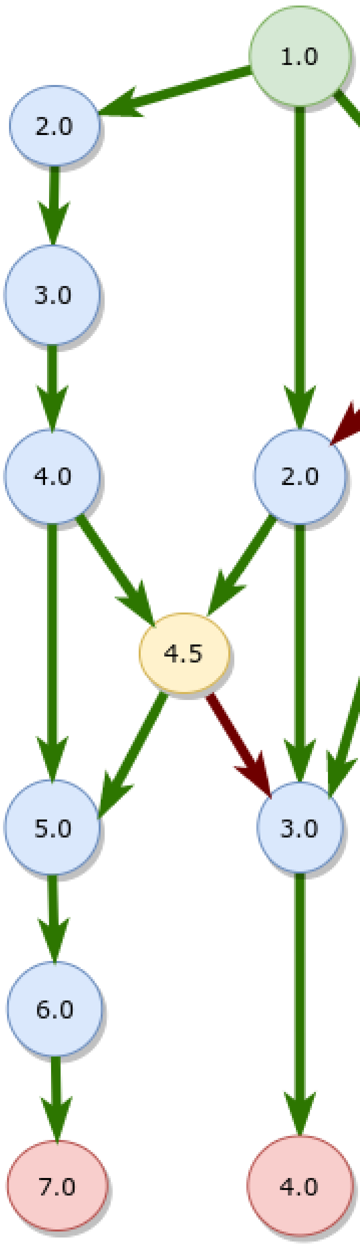

Figure 3: Node versioning to ensure the directed graph is acyclic (DAG). Each node creation requires a node version from the user. A green arrow shows a permitted edge and a red arrow shows a rejected edge.

Appendix C shows a detailed CREATE transaction with the populated fields. The associative array *asset*, contains the immutable data such as the version and reference data of the chapter. From figure 3, node $c_{2.5}$ would have $c_{1.0}$ in the parents array and $c_{3.0}$ in the children array. These represent the edges between the nodes. The node version 2.5 is also immutable to ensure the topological ordering of the DAG is not affected by updates to the data. The metadata can be updated with subsequent transfer transactions of the chapter. For instance, the *payment_pointer* can change if the asset is transferred to a new owner. The royalty is a percentage of revenue that any referencing chapter will pay to the referenced one. The author of a chapter might decide to change this fee for future references if desired.[24]

[24] A change in royalty affects chapters that reference after the change. Previous chapters that referenced before the change will be billed at the previous royalty rate

4.4 Business logic

The preceding section 3.1.1 on decentralisation discussed two service delivery mechanisms, proxy servers and signature libraries, for ensuring that service is delivered to consumers that have paid for it. Both mechanisms have their advantages and disadvantages, but the proxy server mechanism is used on Axone because it has a practical advantage of scalability. Each proxy server functions as a custodian of the encrypted data on the BigchainDB. The custodian is granted the privilege to validate payment and deliver service to a validated consumer. Axone is a custodian by default, but other individuals or organisations can act as custodians if a content creator permits it. The next sections examine how the custodian and the creator interact to secure a digital asset.

Figure 4 shows the flow for encrypting a chapter before publishing it onto the BigchainDB. The entire process happens on the client side. No private keys are transferred over the internet – which eliminates the risk of interception. When a creator publishes a chapter, an Ed25519 signing private key (Ed_D_Sk) is generated. The Ed_D_Sk is required to create a signature for signing off any further transactions (updates and transfer of ownership) on the chapter thus it must be kept safe and secure. The Ed_D_Sk can be reused in the creation of further chapters but, the creator can generate different private keys for each chapter.[25] The signing public key Ed_D_Pk is encoded in the Ed_D_Sk such that only the private key needs to be known by the creator.

Next after the generation of the Ed_D_Sk, the AES key is generated which is used for AES symmetric encryption of the document. The document is encrypted using the AES key. Because the AES key is symmetric, this same key is required to

[25] Generating multiple private keys increases the chances of the keys getting lost. It might be in the creator's best interest to use a few private keys.

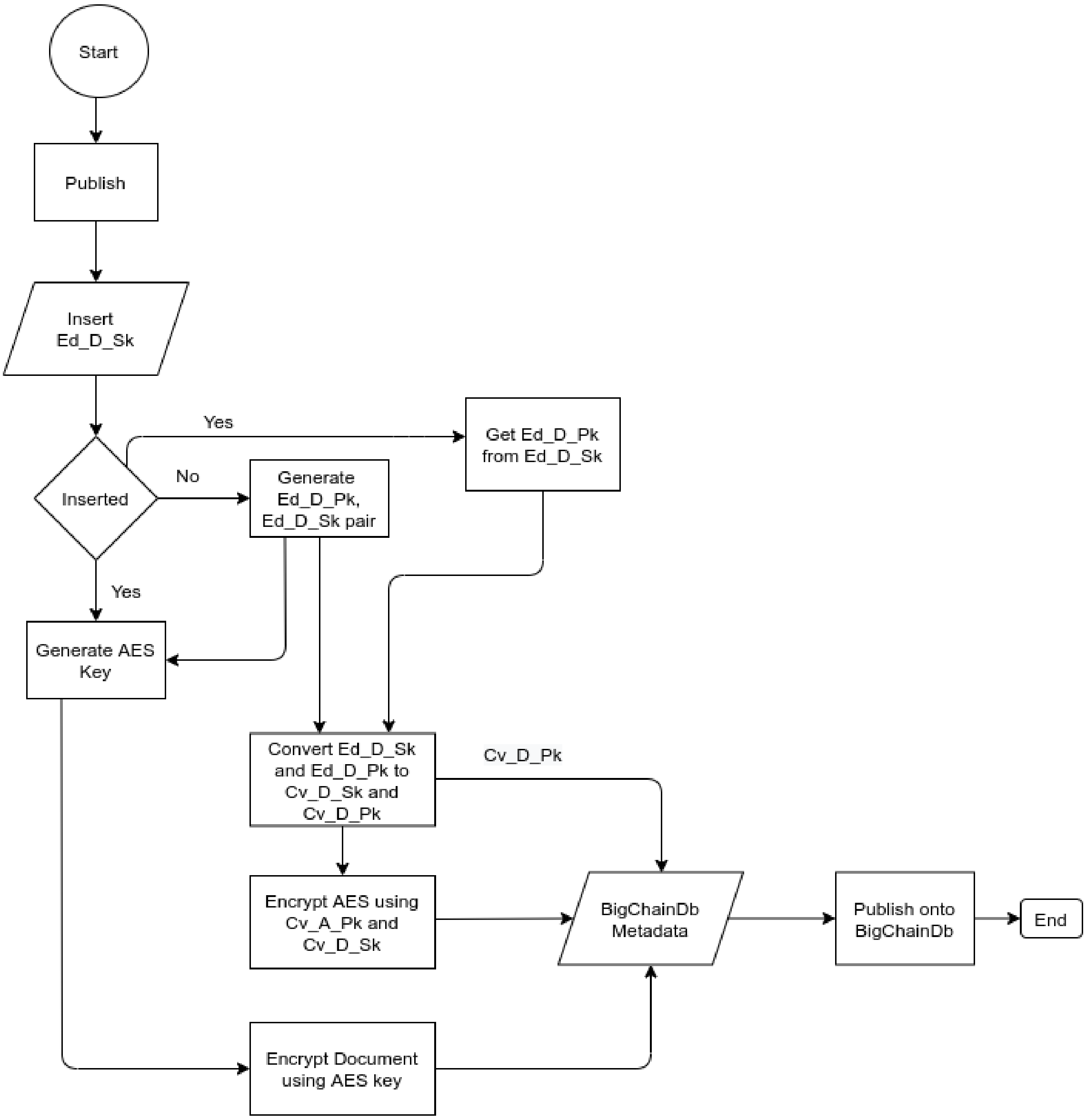

Figure 4: Encryption flow for publishing. Ed_D_Sk stands for ED25519 Signing Private Key for the Document. Ed_D_Pk is its pair public key. Likewise, Ed_A_Sk and Ed_A_Pk stands for the same but the keys are for Axone which is also a custodian. Cv_D_Sk stands for Curve25519 Encryption Private Key for the document.

decrypt the document. Thus to make sure it is used only by the intended party (the custodian in this case), it is asymmetrically encrypted using a function that takes as input the Cv_D_Sk, Cv_A_Pk and the value to be encrypted (the AES key in this case). The Cv_D_Sk is generated from the Ed_D_Sk. It is an encryption private key whereas the Ed_D_Sk is a signing private key.[26] The encrypted document is put as metadata into the BigchainDb transaction for the creation of the asset. Included as metadata is the Cv_D_Pk and the asymmetrically encrypted AES key.

Figure 14 shows the payment confirmation process. After Axone receives confirmation of payments on the website (point number 10), a request is sent to the server to retrieve the chapter's text for the reader. Figure 5 shows the flow for decrypting the chapter on Axone's servers to send the text to a reader who has their payment confirmed. The Cv_A_Sk is securely stored on the server side of Axone. The decryption function takes in Cv_A_Sk, Cv_D_Pk (acquired from the assets' metadata) and the encrypted value which is the AES key. After decrypting the AES key the decrypted chapter can be sent to the reader.

Appendix D shows a detailed transfer transaction containing fields enabling the custodian, Axone, to decrypt the document stored as an encrypted blob in the metadata field. The AES key and Cv_D_Pk are the axone_secret and document_pk fields respectively, in the metadata data structure. The cover_ipfs_path is the IPFS content identifier for the image on the cover the book. The *published* field on the create transaction is not only useful as information for the reader, but also as a means of settling intellectual property disputes by proving that the content was available and in a certain state at that point in time [National Research Council, 2000]. This prevents malicious custodians for example, from copying the work of the content entrusted to their custody. The *royalty* field is a percentage fee paid to the creator's

[26] A signing private key cannot be used for the encryption of documents. It is only used for authorisation of transactions by signing them off.

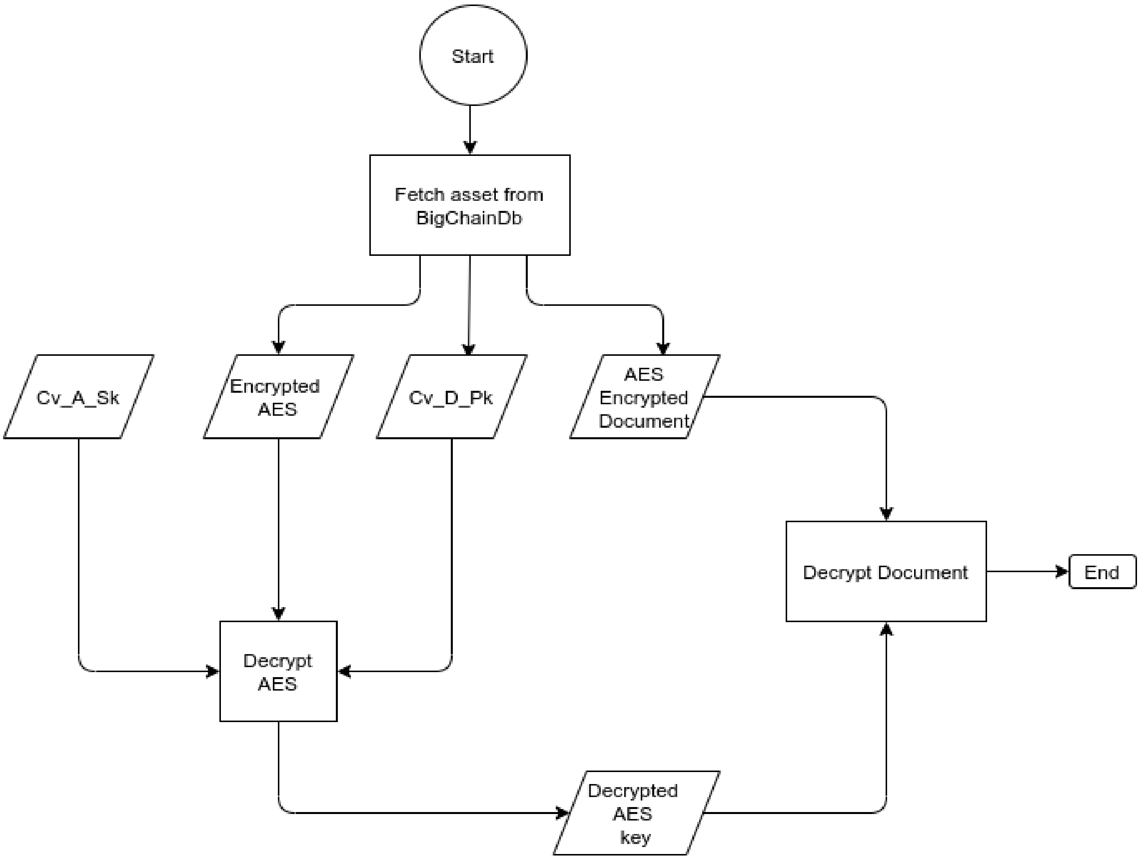

Figure 5: Decryption flow for the document from BigChainDb. The process happens on the custodian's server (Axone in this case). Cv_A_Sk belongs to Axone is safely kept on its servers or any other key management services. Cv_D_Pk is taken from the document metadata. After decrypting the AES key, the document can then be decrypted.

payment_pointer end point by any chapters referencing it. These fields are part of the metadata to enable the content owner to update them and also to enable retrieval directly from the BigchainDB instance without going through a custodian, for external verifiability. Any discrepancy between the BigchainDB metadata and the data served on the client side of the custodian will raise a red flag for tampering of the data.

4.5 The user interface

The UI is the entry point for the authors and the readers. Authors can create their content, publish it, and receive payments through the WM JavaScript API.

4.5.1 UI components

Vue.js has been used for building the user interface. It is an open source JavaScript library which has been increasingly adopted. This guarantees its continued support for the distant future. It is easy to use compared to alternatives such as Angular and React. Most importantly, it is well documented and because it is one of the most used frameworks, many issues encountered have solutions on some of the forums on the internet.

Google Docs have been used as the text editor for authors to write chapters. A plugin was created to integrate Google Docs with the Axone server. Appendix A, figure 10, shows the UI for the Google Docs plugin. In addition to text editing and publishing, authors can add useful metadata to the chapters such as synopsis, detail of characters, and places of interest. These are details useful for understanding the novel and to help other authors write succeeding chapters.

WM is used for payments to the authors. It is a JavaScript browser API that allows the creation of a payment stream from the user to the author. For this to happen, both the author and the reader must set up web monetized wallets for receiving and making payments. The author gets a payment pointer for their wallet that they enter before they publish any content. The payment pointer is stored together with the chapter's text and metadata on the BigchainDB. Figure 12 in Appendix A shows the reader web page. The top right corner shows that payments are being streamed to the author of the chapter being currently viewed.

4.5.2 Writing a chapter

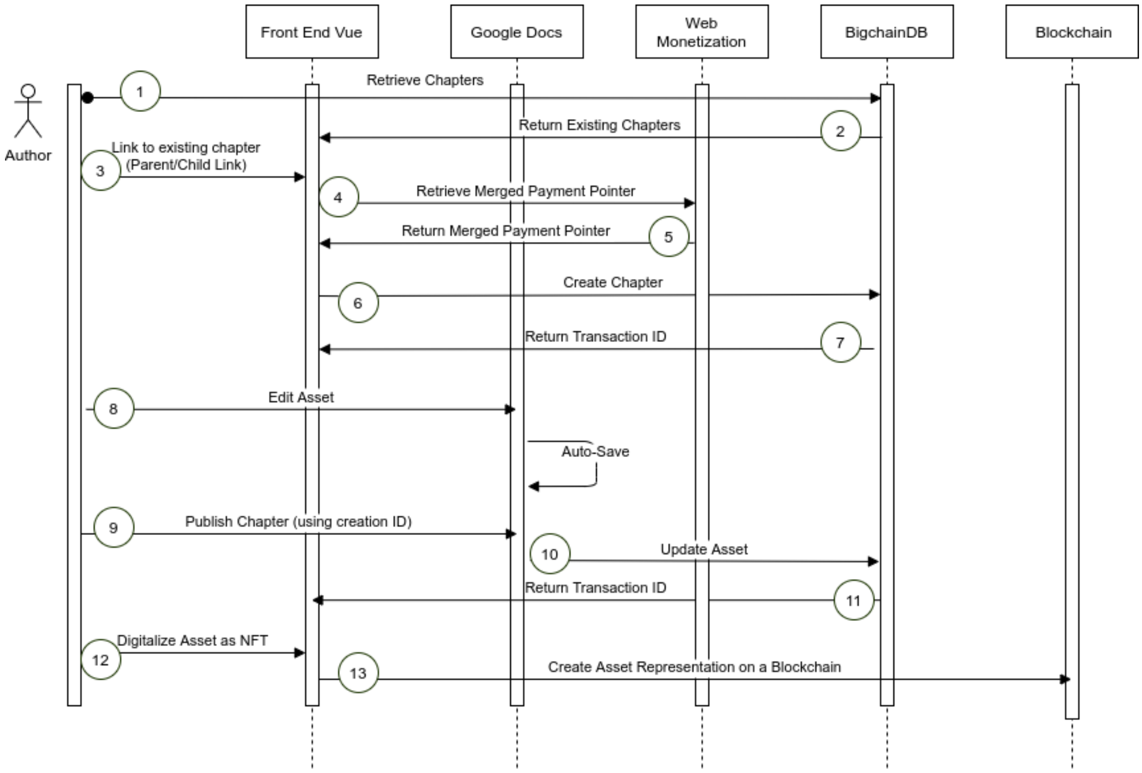

Figure 6: Sequence diagram of the author from creation of a chapter to publication

Figure 6 shows the sequence diagram of the author from the creation to publication of a chapter. Axone does not require a user to sign in, but instead requires a user (author or reader) to have a wallet that supports WM. Each user can be an author or a reader – depending on whether they are viewing content or creating their own content for publication.

Each chapter will be a continuation of a pre-existing book or the first chapter of a book. To create a chapter for a pre-existing book, the author retrieves chapters they have published or which have been published by others on the Axone web application. A succeeding chapter will reference one or more chapters. The reference details are inserted in the CREATE transaction. The royalty percentage to be paid to the referenced chapters is retrieved from the chapter's metadata. Once a chapter is created, two important pieces of data are returned to the user: a private key (which has the public key encoded in it) and the asset id. These two pieces of data will be used to edit the chapter on Google Docs.

When a chapter is created it has no body text. The body text is inserted using the Axone Google Docs addon. In addition to writing the body of the chapter, an author can edit details such as the book and chapter titles, the cover picture (saved on IPFS), and the genres. Once done, the author enters the asset id and the private key that were returned when the asset was created. The asset id can be obtained from the Axone web app, but the private key should be kept safe by the user.

Using this structure, an author can edit the content of the chapter they created. This, however, will only create a newer version of that chapter – but the transaction history of the chapter is kept on the Bigchaindb and can be viewed by the public. Certain fields which are populated on asset creation are immutable, such that the user cannot change the reference details for instance – to avoid paying royalties to referenced chapters.

4.5.3 Reading a chapter

Figure 7 shows the sequence diagram of the reader for reading a chapter. Axone will also not require a user to sign in, but instead will require a user (author or reader) to have a wallet that supports WM. The reader can search for content for the purpose of extending it or for reading it. Either way, the content must be viewed first and the author or reader will stream payments to the author of that content. If there is no more credit in their wallet, the user will not have access to the content.

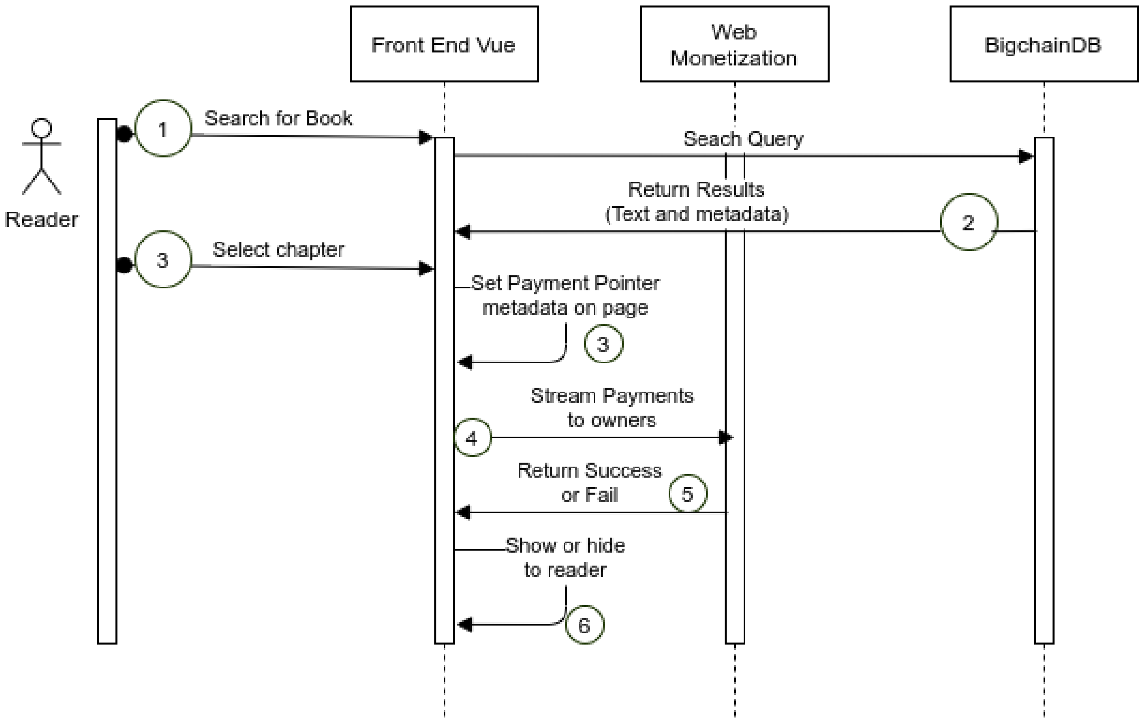

Figure 7: Sequence diagram of the reader from searching for a chapter to viewing it

4.6 System limitations and future work

Ownership affords an owner the entitlement to control. On Axone, authors can control who can read their material by entrusting that validation to a custodian. The custodian will decrypt the document on behalf of the author given that a reader is streaming payments to the authors WMR account. Controlling access of the custodian, however, is not that simple. Section 4.4 has the encryption and decryption logic in detail. In simple terms, the custodian is given a key to a version of the document. The document contents are stored on the bigchaindb and cannot be deleted. This means the custodian will always have the ability to unlock that version of the document. If the author wants to terminate custodianship, a new version of the document should be published but locked with a different key that the former custodian has no access to. The custodian however can still have access to the older versions of that document. Due to the design of Axone and the features of bigchaindb a solution to this is yet to be found which will be part of the future work on Axone.

Ownership also affords an owner the entitlement to alienate. On Axone, authors can transfer a chapter they own to another entity by signing over the chapter to the entity's public key through a transfer transaction. This is facilitated by Axone on the UI as shown in figure 13. The conditions for this transfer have to be settled externally to Axone. In the future the conditions of the transfer, including the transfer value of the chapter, will be handled on a NFT marketplace such as OpenSea. To accomplish this, Axone will create a smart contract on Ethereum which is ERC721 and ERC721Metadata standard compliant and integrate it with OpenSea as shown here [OpenSea, 2021]. This is one example implementation among other blockchains and marketplaces that can be investigated in the future.

5 Conclusion

This thesis presented Axone, a system for the ownership of collaboratively created digital content in the form of written work. Ownership of an object affords the owner entitlements to use, control, encumber, alienate and vindicate. Axone provides authors with these entitlements through asymmetric cryptography, referencing and credit attribution techniques. These techniques are inherently found in blockchain technology. As such, Axone used BigchainDB, a software with blockchain and database properties.

A decentralized system is needed to provide creators with control over their digital content. Decentralization is a property of BigchainDB which rescinds control of digital content from big tech firms. On Axone, digital content is also encrypted using asymmetric cryptography – such that authors can grant or revoke custodianship to any party they wish.

An owner is entitled to the use of an object in order to create revenue. On Axone, this is accomplished through royalty fees. Any reference to a chapter requires a royalty fee to the chapter's author. Only the author is authorised to set the royalty fee – depending on how valuable they perceive their work to be.

Finally, an owner is entitled to vindicate and alienate themselves from an object. On Axone, a chapter can be transferred to another owner using the TRANSFER transaction provided by BigchainDB. Because BigchainDB is immutable, it provides a way for an owner to vindicate their asset in the event of a malicious custodian using the asset for personal gain.

By using a DAG data structure for chapter referencing, Axone successfully provides a mechanism for the ownership of collaboratively created digital content. Further work can be done for the auctioning of chapters in order to transfer ownership.

Currently, agreements on the value of a chapter can be done separately between an author and a buyer. When a valuation is set and the author receives payment, the author can use Axone to transfer ownership to the purchaser. As future work Axone will offer authors the option to list their chapters as NFTs on NFT marketplaces such as OpenSea.

A User Interface Snapshots

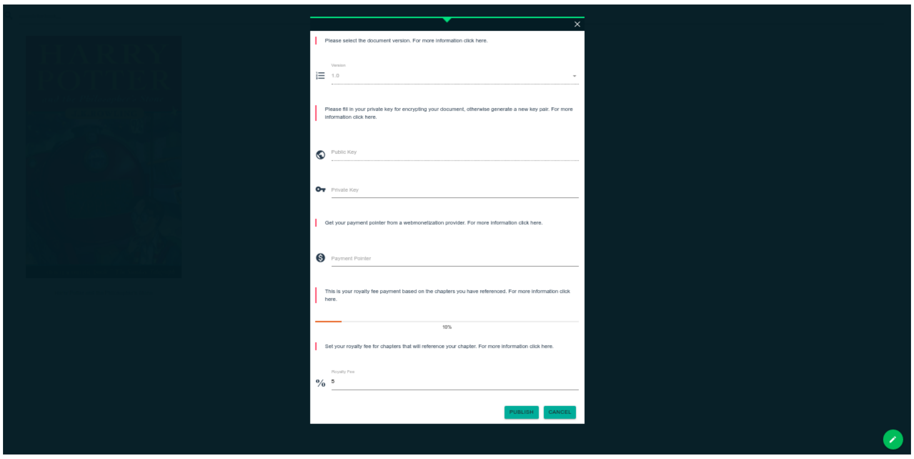

Figure 8: Create a chapter by entering the details on the Axone web app. Initial version number for the first chapter is 1.0. A transaction id is returned to use when editing the chapter on Google Docs.

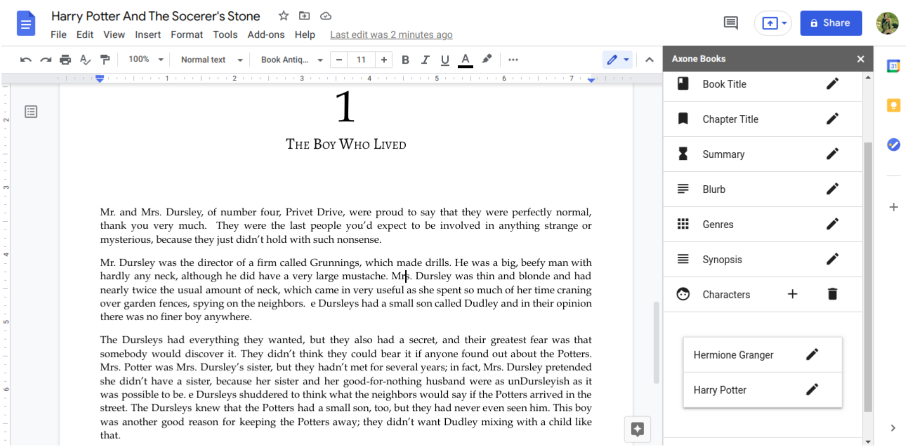

Figure 9: Axone plugin for Google Docs. The author can add details of the novel in the right hand panel such as synopsis, characterizations etc., which might be useful to authors who would like to write further chapter.

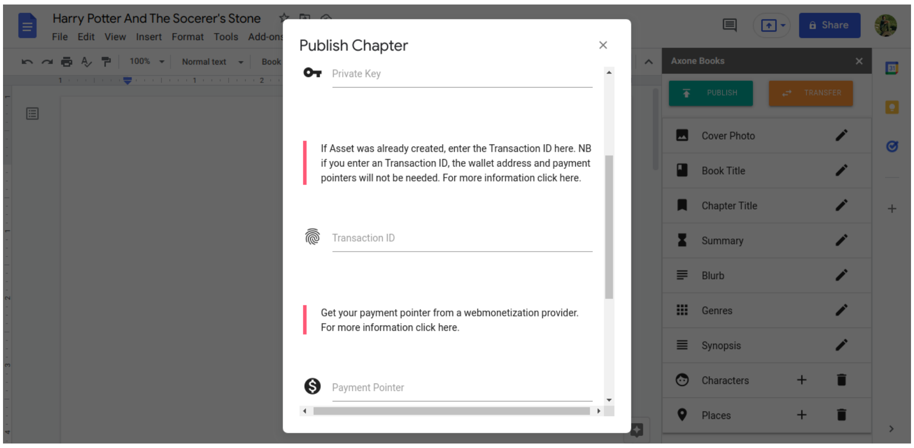

Figure 10: Using the transaction id from the chapter creation, publish the content of the chapter.

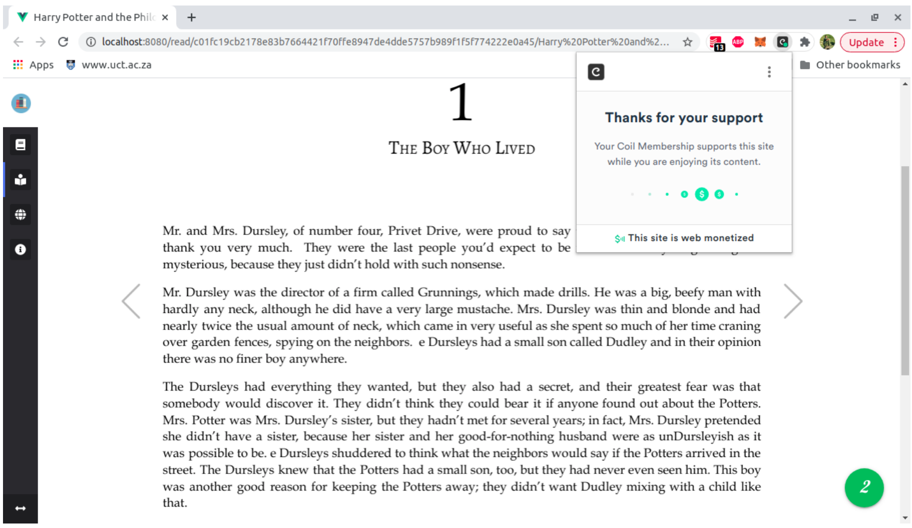

Figure 11: The reader view of a published chapter. The top right corner shows that the web page is monetized and the reader is streaming payments to the authors account.

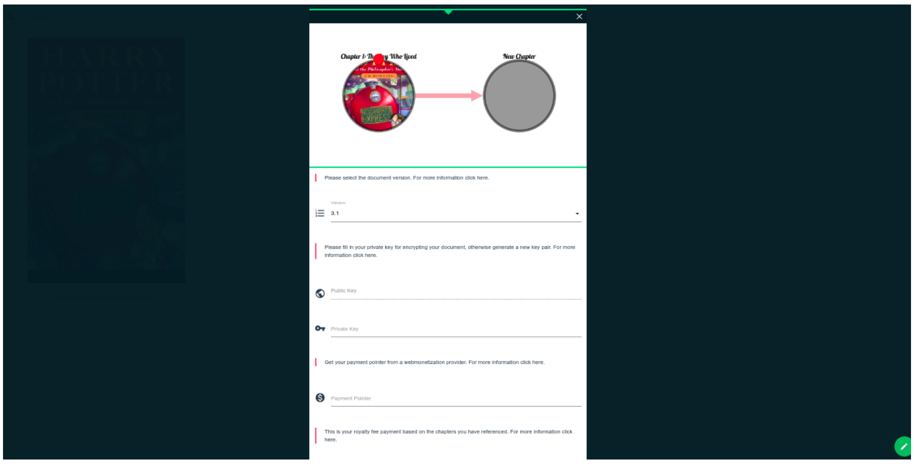

Figure 12: Chapter referencing on the Axone web app. A creator selects a chapter they wish to extend and creates a new node. The version is restricted such that topological sort order is maintained in the DAG.

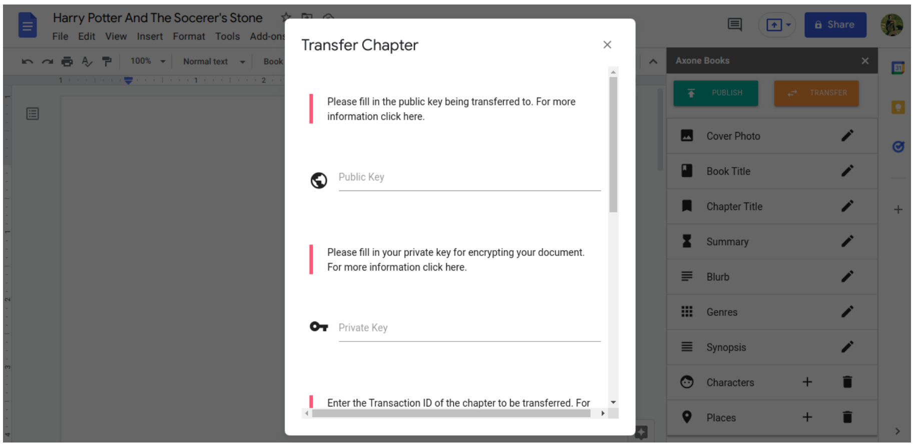

Figure 13: Chapter transfer on the Axone web app. A creator can transfer ownership to another by getting the new owner's public key. The transfer is authorised by entering their own private key and the ID of an unspent transaction.

B Detailed web monetization flow

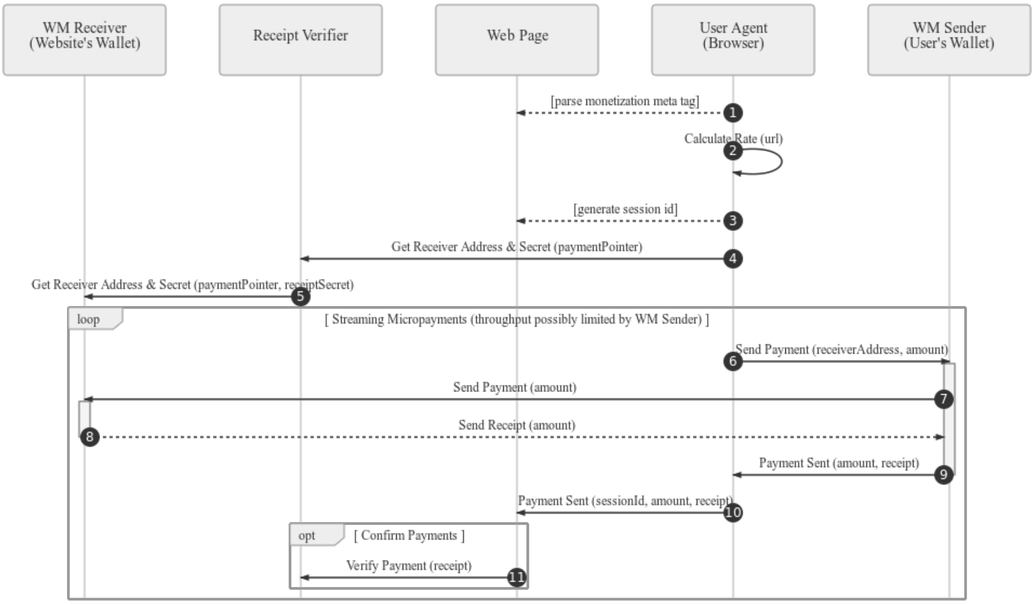

Figure 14: Web Monetization sequence diagram

1. Sites that support Web Monetization include a ¡meta¿ tag containing a payment pointer. The browser (user agent) parses the tag to determine where to send payments.

2. The browser uses its internal Web Monetization agent to calculate an appropriate rate of payments to make to the site. The browser generates a unique session ID for this payment session.

3. The browser fetches a unique destination address and shared secret for the session from the site's payment pointer URL.

4. (Optional) A payment receipt verifier service (operated by the site or a third party) proxies the request and sends a Receipt Secret to generate receipts and Receipt Nonce to include in those receipts to the WM Receiver.

5. With the site's page still in focus, the browser begins initiating payments to the website at the calculated rate from the user's WM provider.
6. The WM provider sends the payment to the WM receiver.
7. (Optional) The WM receiver generates and sends a receipt to the WM provider.
8. The WM provider notifies the browser of successful payments.
9. The browser, in turn, dispatches an event that informs the page of the payment.
10. (Optional) The page confirms payment by sending the receipt to the verifier service.

C Detailed create transaction

```
{
  "inputs":[{
       "owners_before":["5GXqeEXLMiuYoaCUVJTsRejW..."],
       "fulfills":null,
       "fulfillment":"pGSAID9pVEe0wMHdHYHeSR3UI2W..."
   }],
  "outputs":[{
       "public_keys":["5GXqeEXLMiuYoaCUVJTsRejW..."],
       "condition":{
           "details":{
               "type":"ed25519-sha-256",
               "public_key":"5GXqeEXLMiuYoaCUVJTsRejW..."
           },
           "uri":"ni:///sha-256;FfGK8ZM-x1qriSC..."
    },
```

```
      "amount":"1"
     }],
    "operation":"CREATE",
    "metadata":{
         "document_pk":"5GXqeEXLMiuYoaCUVJTsRejW...",
         "tags":"Axone Books",
         "payment_pointer":"$ilp.uphold.com/2gd3JwQG8JUN",
         "royalty":5,
         "published":"Tue Jul 20 2021 21:36:29 GMT+0200"
    },
    "asset":{
         "data":{
             "version":"2.5",
             "parents":["873a4f1493e549f5c3290380d60e7d..."],
             "children":[],
             "parents_transactions":["3e121c5dda88f59f...."],
             "children_transactions":[],
             "published":"Tue Jul 20 2021 21:36:29 GMT+0200"
       }
    },
    "version":"2.0",
    "id":"57187dbbad1ae4807fe0708be9d05a235741ae23..."
}
```


D Detailed transfer transaction


```
{
```

```
    "inputs":[
        {
            "owners_before":["5GXqeEXLMiuYoaCUVJTsRejWr..."],
            "fulfills":{
                "transaction_id":"38546555f5b3138be4...",
                "output_index":0
            },
            "fulfillment":"pGSAID9pVEe0wMHdHYHeSR3UI244..."
        }
    ],
    "outputs":[
        {
            "public_keys":["CFr6w4qyd7vR55S7EQTT2vF..."],
            "condition":{
                "details":{
                    "type":"ed25519-sha-256",
                    "public_key":"CFr6w4qyd7vR55S7EQTT..."
                },
                "uri":"ni:///sha-256;EfzI0Rq4UCJy_Cxs5vqst..."
            },
            "amount":"1"
        }
    ],
    "operation":"TRANSFER",
    "metadata":{
        "tags":"Axone Books",
        "document_pk":"CFr6w4qyd7vR55S7EQTT2vFm3q...",
```

```
      "axone_secret":"8Zvaiqqmrqb1cxToSRJGkARFWw...",
      "axone_nonce":"7L3SohCaUd1YF8J5NhyHxFedDbdZyF4Gq",
      "payment_pointer":"$ilp.uphold.com/2gd3JwQG8JUN",
      "royalty":5,
      "properties":{
          "synopsis":"Harry Potter lives...",
          "characters":"[...]",
          "places":"[...]",
          "book_title":"Harry Potter and the ...",
          "summary":"Harry is now almost eleven ...",
          "blurb":"When mysterious letters start ...",
          "chapter_title":"Chapter 2: The Vanishing Glass...",
          "genres":[...],
          "cover_ipfs_path":"QmeW9sGrFsAB5M2kyvJH..."
      },
      "blob":{...}
    },
    "chapter_title":"Chapter 2: The Vanishing Glass",
    "book_title":"Harry Potter and the Philosop...",
    "cover":"QmeW9sGrFsAB5M2kyvJHRxniMX62cfYv...",
    "blurb":"When mysterious letters start arriving...",
    "genres":["romance","dystopian","fantasy"],
    "published":"Fri Oct 01 2021 13:43:39 GMT+0200"
  },
  "asset":{
    "id":"617fa4de4e8df4adf0bb54b164ad6240898..."
  },
```

```
  "version":"2.0",
  "id":"ac596b71202c4c86003823d2da420e758e1b3f..."
}
```


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