Kyokai: Mapping the Path to Converging Physical and Digital Worlds

Tri Pham, Huy Nguyen, Nam Do, and Thien Nguyen
KardiaChain

***Abstract*—This whitepaper proposes a comprehensive solution for bridging the gap between the physical and digital worlds, aiming to create a convergent mapping of real-life elements onto the digital verse. The solution focuses on four key components: People, Items, Locations, and Activities, and sets a standard process for their integration. By enabling this transformation, we unlock a range of benefits, including improved accessibility, scalability, and engaging experiences.**

The solution leverages emerging technologies such as VR/AR, NFC+, 3D modeling, and blockchain infrastructure. The use of blockchain ensures transparent ownership records and facilitates the development of a new exchange market and economic activities in both realms.

Through ongoing research, development, and collaboration, the implementation of this solution is progressing toward a future where the physical and digital worlds seamlessly merge. With the potential for mass adoption within the next decade, this convergence has the power to reshape society, revolutionize industries, and unlock new realms of human potential.

In conclusion, by bringing the physical and digital worlds together, we create a transformative scenario that opens up new possibilities for immersive, interconnected, and inclusive

I. INTRODUCTION

1.1. Phygital

In recent years, the metaverse has gained popularity with the rise of virtual spaces like social networks, games, and AR/VR [1]. However, solely focusing on virtual environments is not sustainable due to the prevalence of fake identities and actions. In actuality, not all humans subscribe to real-world escapism. To make virtual spaces work, there needs to be an online-offline convergence that connects the digital and physical worlds [2].

For instance, a Lamborghini owner should be able to bring their luxury car into a virtual racing game, with the car's unique identity and ownership assigned to their avatar. Changes in real-life ownership should also be reflected in the virtual world.

This convergence requires a comprehensive solution that can safely and conveniently map anything from the real world to the digital world and vice versa. The ultimate goal is to create a "phygital" solution that bridges the gap between the physical and digital worlds. Although there have been efforts to achieve this [3] [4], such as the physical-backed token (PBT) standard, they still need to gain more traction. This paper outlines an end-to-end solution to make this goal a reality.

1.2. Challenges

The challenge in creating a convergent solution lies in the complexity of our real world, with many facets that need to be accounted for. For instance, transforming a normal routine day of a father taking his son to school requires identifying:

- Their digital identities,
- Belongings such as the car, clothes, or accessories,
- Locations of their house and school, and
- Travel details such as path and speed

A comprehensive solution must seamlessly accommodate all of these factors. Given the above objective, the ideal design needs to satisfy the following requirements:

- Functionality:
  - Simple and concrete process of mapping the physical world to digital.
  - Clear decision on what to transform.
  - Unique identification of physical items in digital form, i.e. DNA of the physical counterpart.
  - A combination of many digital versions could mimic the physical counterpart.
- Security:
  - Hack-proof, counterfeit-proof, and censor-proof,
  - Safely maintain the unique link and the contextual relationship between each map from the physical world to its digital counterpart, regardless of possible real-time changes.
- Privacy:
  - Protect user's privacy
  - Offer customizable settings to fully manage their privacy, e.g. whether they want to share or hide their digital presence
- Scalability:
  - Scale without compromising performance
  - Able to match the vast number of objects in the physical world.
- Decentralization:
  - In an open metaverse, no central authority should control one's identity or actions. Decentralization allows the community to decide and adjust the level of control.
  - For example, If Facebook's metaverse deactivates someone's account or identity, they would disappear from the digital space, which is not reflective of the real world.

II. OVERVIEW DESIGN

A comprehensive solution should transform anything (e.g. items or locations) and anyone from the physical world to the digital world. This will reflect real life into the digital world,

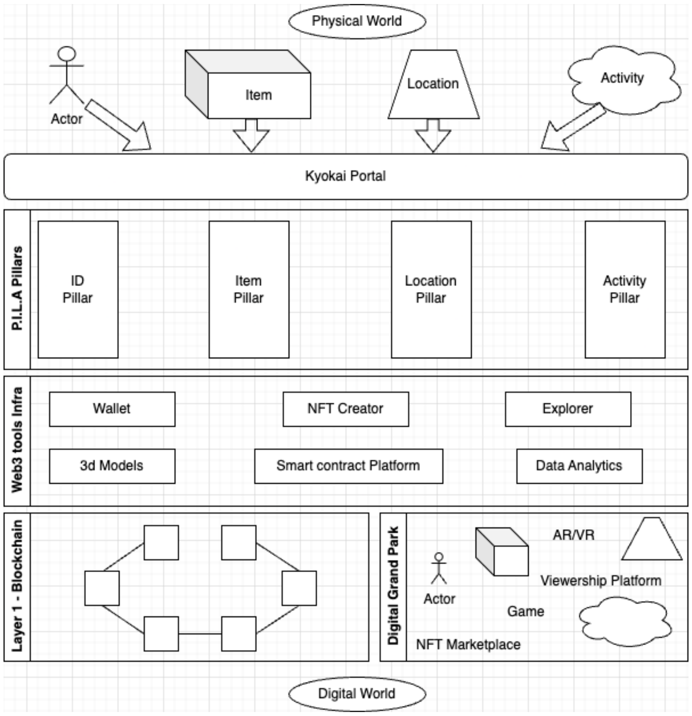

Fig. 1: *Physical to Digital world by Kyokai portal*

allowing people to share their everyday lives while maintaining their privacy. The goal is to allow people to share their everyday lives in the digital world while managing their privacy effectively. With the aforementioned requirements in mind, our high-level design is presented in the below diagram (Fig. 1), which consists of 4 main components: layer-1 Blockchain Infrastructure, web3 infrastructural toolset, the P.I.L.A Pillars, and Digital Grand Park and Beyond.

2.1. Layer-1 Blockchain Infrastructure

The solution relies on a layer-1 blockchain infrastructure for decentralization and security. Different types of blockchain can be used, each with their own purpose and consensus mechanism. From permissioned to permissionless, from public to consortium to private, and different consensus mechanisms such as Proof-of-Work, Proof-of-Stake, or Round Robin, etc. In general, the infrastructure needs to be fast, cheap, and tamper-evident. It serves as a master database for smart contracts to control digital objects. For example, mapping a physical Toyota in the real world to a digital world will create a non-fungible token (NFT) or a DNA of this car in the metaverse.

2.2. Web3 Infrastructural toolset

On top of the layer-1 blockchain infrastructure comes a layer of tools and accessories to allow users access and manage certain parts of the blockchain.

- Wallets store users' identity (public address and history), items (NFT), money (tokens), and other data and can be accessed through mobile applications, browsers, or extensions.
- Explorers provide a one-stop-shop for information and settings on the blockchain.
- Smart contract IDEs provide a suite of tools and features that make it easier for developers to create, test, and deploy smart contracts.
- Other tools, such as NFT creation and data analytics platforms, may also be available.

2.3. The P.I.L.A. Pillars

The P.I.L.A. comprises four core components that fully represent real life in the digital verse: *People*, *Item*, *Location*, and *Activity*.

- *Person* - the WHO - uniquely identifies a real person in the metaverse, i.e. DNA of that person.
- *Item* - the WHAT - uniquely identifies an item on the metaverse, created using DNA of its physical version. Items can be owned by the aforementioned component - *Person*.
- *Location* - the WHERE - uniquely identifies a real-world location and maps it into the digital verse, potentially using 3D models that reflect the location's features and characteristics. It should be able to interact with Person and Item, such as allowing check-in or recognizing them in range.
- *Activity* - the HOW - transforms real-world activities into their digital versions, such as moving an item or tree in a park. These actions can involve *Identity*, *Item*, and *Location*.

Each pillar alone represents a significant portion of daily life, and when combined in different configurations, they can fully represent real life in the digital verse.

2.4. Digital Grand Park and Beyond

Once the portal successfully onboards the physical world onto the digital verse, there is a need to serve the life on the digital verse, such as AR/VR integration, gamification, marketplace to exchange items, viewership platform, or any other infrastructure for interacting with such activities.

Several park-like open virtual spaces are being developed by various teams around the world, namely the OM Museum District by Punk6529. Gamification is also implemented across the blockchain space, such as Defi Kingdom, Layer3 and Philand. AR/VR platforms are more accessible than before with the growth of Decentraland and Spatial. This is to say that the conditions for life on the metaverse is prime, awaiting for the portal to open.

III. Detailed Design

3.1. Layer-1 Blockchain Infrastructure

Layer-1 blockchains are the foundation of blockchain networks, responsible for creating and validating blocks, executing transactions, and maintaining decentralized ledgers using cryptographic algorithms. They enable the development of secure and transparent smart contract systems. Some of the criteria to consider when choosing a blockchain for Kyokai might include:

- A proven track record with a history of highly secure and reliable operation
- High performance and scalability to handle a large volume of transactions and data
- Robust smart contract functionality for flexible and secure execution of transactions
- Interoperability with other blockchains and legacy systems

Choosing the right Layer-1 blockchain for the phygital solution is critical and requires considering cost, performance, scalability, security, and decentralization. A trilemma exists in blockchain technology regarding the trade-off between security, performance, and decentralization for each Layer-1 blockchain, which affects the critical features of the phygital solution. The primary elements that influence the trilemma are blockchain types, consensus, and virtual machines will be discussed in below sections.

3.1.1. Blockchain Types:

Permissioned vs. Permissionless: Permissionless blockchains are open to everyone and fully decentralized, while permissioned blockchains are closed networks limited to designated parties and partially decentralized. Permissionless blockchains prioritize transparency, open source development, anonymity, lack of central authority, and use of tokens as incentives. Permissioned blockchains prioritize controlled transparency, development by private entities, lack of anonymity, and decision authorization by a private group. At the simplest level, the distinction lies in whether the network is open for anyone to participate i.e. permissionless or limited only to designated participants i.e. permissioned.

Public vs. Private vs. Consortium vs. Hybrid: Blockchain infrastructure can be classified into public, private, consortium, and hybrid, depending on the permission settings. Public is permissionless, while private is a single owner inviting others to join. Consortium is governed by a group, while hybrid networks are interoperable and can scale across various entities and consortia. A ”blockchain of many blockchains” is envisioned in the long term, similar to the internet of many intranets. Choosing the appropriate blockchain infrastructure type is crucial for meeting the demands of the entire solution.

3.1.2. Consensus: A consensus mechanism is a set of rules that enable nodes in a network to agree on the state of a blockchain. Validation by multiple nodes ensures the correctness of each transaction before adding it to the blockchain, making it tamper-proof. Choosing a consensus mechanism will impact the blockchain trilemma, as different mechanisms prioritize security, scalability, and decentralization differently. This can affect the overall performance of the blockchain. We will discuss three significant consensus mechanisms and their variations in the following part.

- Proof-of-Work (PoW) is a consensus mechanism with the Bitcoin network [5] as a famous implementation, where nodes compete to solve complex mathematical puzzles to validate transactions and add new blocks to the chain. PoW is secure but not very scalable
- Proof-of-Stake (PoS) is a less energy-intensive consensus mechanism where nodes are chosen to validate transactions based on the amount of native token they hold and are willing to stake as collateral. Delegated Proof-of-Stake (DPoS) is a variant of PoS where users vote for delegates responsible for validation, and Byzantine Fault Tolerance (BFT) is used in some permissioned blockchain networks. PoS is more scalable but may compromise decentralization.
- Proof-of-Authority (PoA) is a consensus mechanism used in some private and consortium blockchain networks where a group of trusted nodes validate transactions, and it is more efficient but less decentralized.

3.1.3. Blockchain Virtual Machine (VM): Blockchain Virtual Machine (VM) is a software environment that runs on a blockchain network and enables the execution of smart contracts. The most popular Blockchain VMs are:

- Ethereum Virtual Machine (EVM): The EVM is the most widely used blockchain VM specifically designed for the Ethereum network. It is a Turing-complete virtual machine, meaning that it can execute any arbitrary code, as long as it is within the gas limit set by the Ethereum network. The EVM is responsible for executing smart contracts written in Solidity, the main programming language used for developing smart contracts on the Ethereum network. It operates on a stack-based architecture and has its own bytecode format.
- WebAssembly Virtual Machine (WASM): The WebAssembly virtual machine is a cross-platform virtual machine designed to run on the web. It is a low-level virtual machine that can execute code written in multiple programming languages, including C++, Rust, and Go. WASM is not specific to any blockchain network, but it can be used to run smart contracts on any blockchain that supports it. Some blockchain networks, such as Polkadot, use the WASM VM to execute smart contracts.

In addition to these, there are several other virtual machines that have been developed for specific blockchain networks or use cases, such as the Bitcoin Script Virtual Machine (BSVM) and the Hyperledger Fabric Chaincode VM. Each VM has its own strengths and weaknesses and is optimized for different use cases.

3.1.4. The ideal blockchain infrastructure: KardiaChain [6] is an ideal blockchain infrastructure for Kyokai, offering a secure and scalable hybrid solution of public and private blockchain with interoperability, high performance, and low transaction costs. It uses the BFT DPoS consensus algorithm, integrates with Ethereum, and has a strong focus on privacy and data protection, offering features such as zero-knowledge proofs and ring signatures to enable anonymous transactions. Using the Proof of Stake consensus algorithm, it reduces energy consumption and computational power, while providing a high level of security and Byzantine fault tolerance.

3.2. Web3 Infrastructural toolset

On top of the layer-1 blockchain infrastructure comes an application layer, consisting of tools and accessories to allow users access and manage certain parts of the blockchain.

3.2.1. Wallets: Wallets or account management tools allow users to create, access, and manage their accounts on the blockchain. The wallet will need to balance three key factors: decentralization, security, and convenience.

Decentralization ensures that users maintain ownership and control over their accounts. This means that the wallet should not have full control over the user's private keys, and users should have the ability to move their funds to other wallets if they wish to do so. Security ensures users' funds are safe and protected from unauthorized access. The wallet should implement robust security measures such as multi-factor authentication, encryption, and backup and recovery options. Convenience ensures users can easily manage their accounts without being overwhelmed by complicated technical procedures. The wallet should have a user-friendly interface and provide easy-to-understand instructions for creating, accessing, and managing accounts. Additionally, the wallet should be compatible with multiple devices and platforms to ensure broad accessibility for users.

By balancing these three factors, the wallet can provide a comprehensive solution for users to manage their accounts on the blockchain with confidence and ease. Here are some of the technical aspects that would need to be considered:

- Private Key Management: One of the core principles of blockchain is the ownership and control of private keys. The wallet should be designed to ensure that users have full control over their private keys, and these keys are not stored centrally on any server. Instead, the wallet should use a hierarchical deterministic (HD) wallet architecture that generates new addresses and private keys for each transaction, ensuring that the user's funds are secure.
- Multi-Factor Authentication: The wallet should implement multi-factor authentication (MFA) to protect user accounts from unauthorized access. The wallet can use techniques such as biometrics, SMS verification, or email verification to ensure that only the authorized user can access the account.
- Recovery options: Apart from other traditional methods like seed phrases, social recovery is an exciting approach that enables users to recover their accounts by leveraging their social network, such as their friends or family members, instead of relying solely on a single device or private key.
  - One way to implement social recovery technology in the wallet is to use Shamir's Secret Sharing Scheme (SSSS), which divides a user's private key into multiple parts or shares, and distributes them among trusted contacts. The user can then recover their private key by collecting a predetermined number of shares from their trusted contacts. This approach ensures that no single person or entity can access the user's private key.
  - Another approach to social recovery technology is to use a decentralized key management system (DKMS), which allows users to delegate key management to a network of trusted nodes. These nodes can then collaborate to recover the user's account if they lose access to their private key.
  - In both cases, social recovery technology can be implemented in a decentralized manner, with no single entity controlling the recovery process. This ensures that the user's privacy and security are maintained while still providing a convenient and accessible way to recover their account.
- User-Friendly Interface: The wallet should be designed with a user-friendly interface to ensure ease of use for users who are not crypto-savvy. The wallet should include simple instructions for creating, accessing, and managing accounts, as well as visual aids such as graphs and charts to help users understand their account activity.

Overall, the wallet should be developed using a decentralized approach, with user-owned private keys and multi-factor authentication to ensure security. The wallet should also provide user-friendly features such as backup and recovery options and a simple interface, ensuring convenience. By taking these technical considerations into account, the wallet can provide a comprehensive solution for users to manage their accounts on the blockchain.

3.2.2. Explorers: A blockchain explorer is a web-based interface that allows users to view and interact with data on the blockchain. It should aim to make blockchain technology accessible to the masses by providing a user-friendly and gamified interface. However, the existing blockchain explorers often use technical language and financial terms, making it difficult for the average person to understand and explore the blockchain. This lack of accessibility can hinder the adoption of blockchain technology by the masses. Therefore, an ideal Kyokai explorer should offer an enjoyable and user-friendly experience, along with fulfilling the basic requirements of regular blockchain users. Such as:

- Robust Search Functionality: allows users to easily search and find information on the blockchain, including transactions, blocks, and addresses.
- Real-Time Update: provides latest transactions and blocks on the blockchain, ensuring users always have access to the latest blockchain activities.
- Multichain Compatibility: provides users with a comprehensive view of all the different blockchain ecosystems.

Additionally, the Kyokai explorer would provide:

- User-Friendly Interface: offers a simple and intuitive interface that is easy to use, even for non-technical individuals. It should avoid technical jargons and use non-financial terms to explain the blockchain.
- Enjoyable Narrative: tell a compelling story yet easy to understand. Humans, by nature, make sense of everything around them through stories. This will make Kyokai explorer become a true gateway for people onto Web3 and blockchain.

- Gamification: makes exploring the blockchain fun and engaging. This can include earning rewards for exploring the blockchain, leveling up, and unlocking achievements.

In conclusion, the Kyokai explorer is an essential component to bridge the gap between the blockchain and the masses. By providing a user-friendly and gamified interface, it makes exploring the blockchain fun, engaging, and accessible to everyone.

3.2.3. Smart contract Integrated Development Environment (IDE): The IDE plays a vital role in the development process as it enables developers to create smart contracts efficiently, test them on a local network, and deploy them on our blockchain. Additionally, it provides a suite of development tools and features such as code highlighting, debugging, testing frameworks, and version control to ensure high-quality code and streamlined development processes.

Several existing IDEs such as Remix, Truffle, and Ganache provide a comprehensive suite of development tools and features for building and testing smart contracts on blockchain platforms like Ethereum. While these IDEs are excellent for general-purpose blockchain development, they do not cater specifically to NFTs and NFCs. NFTs and NFCs are unique digital assets that require specialized tools and features for creation, management, and deployment. For example, an IDE for NFTs and NFCs should have built-in tools for creating and managing 3D models, biometric data, and NFC chips. The IDE should also enable developers to map specific NFTs to NFC chips and manage the mapping throughout the lifecycle of the asset.

The IDE should be designed to cater to the unique needs of the four pillars, for NFT and NFC development, such as:

- NFT Creation: provides a platform for developers to create NFTs with built-in tools for 3D modeling, biometric data management, and NFC chip mapping.
- NFC Mapping: enables developers to map specific NFTs to NFC chips and manage the mapping throughout the lifecycle of the asset.
- Template Management: provides pre-designed templates for NFT creation that enable developers to create assets efficiently and with minimal effort.
- Version Control: provides version control features that enable developers to track changes to their NFTs, revert to previous versions, and collaborate with other developers.
- Debugging: helps developers to identify and fix issues in their smart contracts.
- Deployment: ensures secure and transparent transactions when deploying NFTs to our blockchain.

Our desired IDE is a specialized tool designed to cater to the unique needs of NFT and NFC development. This IDE provides a suite of specialized features such as NFT creation, NFC mapping, template management, version control, debugging, and deployment, enabling developers to create high-quality smart contracts efficiently and effectively. By having a specialized IDE, Kyokai can optimize the development process, improve developer convenience and productivity, and ultimately deliver better solutions for bridging the physical and digital worlds.

3.2.4. Data Analytics: Many existing blockchain analytics tools are built for specific blockchain platforms and focus on financial transactions, such as tracking cryptocurrency transactions, detecting fraudulent activity, and more. Examples of popular blockchain analytics tools include Chainalysis, Bitquery, and Crystal Blockchain. While these tools can provide valuable insights for businesses, they are limited in their scope and do not fully capture the potential of blockchain technology. We recognize that blockchain technology has the potential to digitize more than just financial transactions and has developed a comprehensive analytics tool that reflects this understanding.

A comprehensive data analysis tool for Kyokai is designed to support the core solution, which aims to digitize four aspects: people, items, locations, and activities. As such, the analytics tool should be developed with the features to analyze the four pillars' data. This includes analyzing, identifying trends, and extracting valuable insights into the four aspects. In addition to these features, the analytics tool also includes the following:

- Real-time Data: provides real-time data analysis, allowing for quick decision-making and immediate action.
- User-friendly Interface: be accessible to users with varying levels of technical expertise.
- Customizable Dashboards: allows for the creation of customizable dashboards, allowing users to view data in a way that is meaningful to them.
- Secure Data Storage: All data is stored securely on the blockchain, ensuring the privacy and security of users' data.

While there are existing blockchain analytics tools available, we recognize that its solution requires a more comprehensive analytics tool that reflects the unique digitalization goals of its solution. By developing our own Kyokai analytics tool, we can gain valuable insights into how users interact with its solution and can use this information to optimize its solution. Furthermore, by using our own analytics tool, we can ensure that data is analyzed in a way that is aligned with its solution's goals and objectives.

3.2.5. NFT Creation platform: The NFT Creation platform or as we would like to call it - The Canvas, is a place for both artists and art enthusiasts. The Canvas is a crucial component, providing a platform to create, showcase, and exchange digital collectibles in a transparent and secure manner. Unlike traditional marketplaces that focus on the financial aspect, The Canvas is designed to highlight the collectible aspect of digital items, emphasizing digital ownership and unique attributes. To achieve this goal, The Canvas will represent unique digital assets, such as artwork, music, and even virtual real estate; via Non-Fungible Tokens (NFTs) stored on-chain, providing a transparent and tamper-proof record of ownership and transaction history.

One of the key requirements for The Canvas is to move away from the financial aspect of trading, which can be a barrier for entry to many potential users. Thus, The Canvas will provide tools for creators to easily design and mint their own NFTs, removing technical barriers and allowing anyone to participate in the digital collectible ecosystem.

Here is an example of how The Canvas might work in practice:

- Users creates a digital artwork using their preferred software or application. They upload the artwork to The Canvas and use the provided tools to mint an NFT that represents the artwork.
- The NFT is stored on-chain and available on The Canvas marketplace.
- Other users can browse the marketplace and purchase the NFT via on-chain transactions.

Overall, the Canvas will provide a user-friendly and accessible platform for creating, showcasing, and exchanging digital collectibles. By emphasizing digital ownership and unique attributes, rather than the financial aspect of trading, The Canvas will open up new opportunities for creators and collectors alike.

3.2.6. Conclusion: Having a reliable and efficient Web3 infrastructure toolset is crucial for the success of any blockchain-based solution, including Kyokai. By providing a secure and user-friendly wallet, an intuitive and specialized IDE, a robust blockchain explorer, a comprehensive NFT creation platform, and powerful analytics tools, developers and users will be able to easily create and manage digital assets and transactions on the blockchain. With these tools at our disposal, Kyokai can successfully bridge the gap between the physical and digital worlds and create a new paradigm for asset ownership and management.

3.3. P.I.L.A. Pillar Transformation

P.I.L.A., which stands for Person, Item, Location, and Activity, is a foundational concept within Kyokai's innovative solution. P.I.L.A. represents the four key pillars that Kyokai aims to digitize in order to bridge the physical and digital worlds seamlessly. By capturing and digitizing information about individuals, items, locations, and activities, Kyokai enables a comprehensive understanding and representation of the physical world within the digital realm. This section will discuss the procedure needed to transform all the P.I.L.A. from physical to digital.

All pillar transformations require three essential steps:

Step 1: A unique physical ID (PID) of the object must be created using specialized processes, tools, hardware, or apps.

Step 2: A digital ID (DID) of the object in the digital world must be created, which will be recorded in blockchain. This process will require the use of different platforms and tools.

Step 3: The physical ID and digital ID must be linked together securely, and the link must be immutable.

Each of the pillars will require separate customized actions and unique interactions between them, which the platform must support individually.

3.3.1. Identity Pillar: Our goal with the identity pillar is transforming any physical identity (PID) in the real world to a unique identity in the digital verse (digital identity - DID). Pairing physical and digital identities enables tracking and managing online activities, combating cybercrime and fake identities. Digital identities streamline transactions and activities, enhancing convenience and security for individuals and organizations.

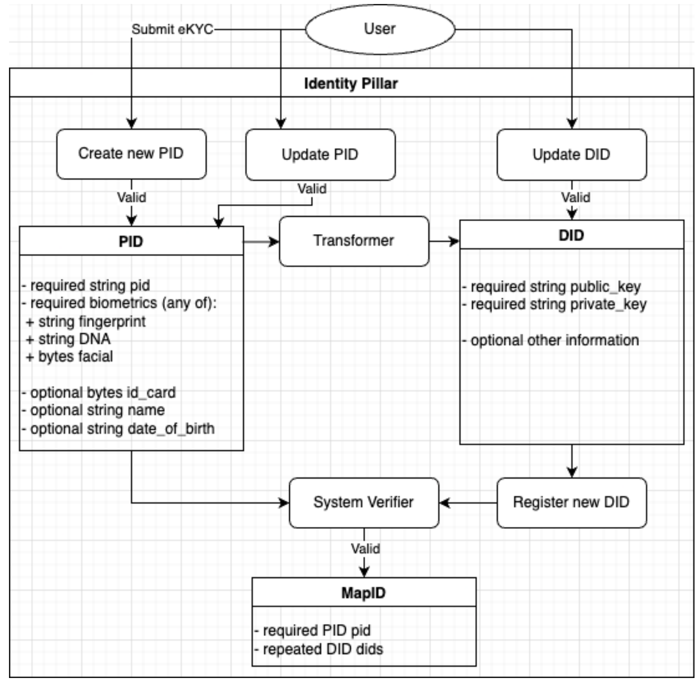

Fig. 2: *Standard process of Identity Pillar*

Requirements:

- The Input is a unique PID in various forms, such as ID cards, passports, facial images, fingerprints, and DNA, which represent individuals in the real world. The desired Output would be a unique and immutable DID in cryptographic form, such as a public/private key pair or RSA pair, and a unique map link between PID and DID.
- The link between PID and DID must be both unique and immutable. By unique, this mapping link means that no two digital identities are the same, just as so for their two physical identities. In terms of immutability, this digital identity should not be altered or changed.

Process: As described in the below diagram (Fig. 2), there are a few important processes related to this identity pillar.

- *Create a new PID:* Users submit eKYC documents to prove who they are. Documents should satisfy requirements such as biometrics and guarantee uniqueness. Then, the system verifies whether those documents are valid and do not exist before. If it already exists, the system will reject this PID. If it does not exist, a new PID will be created. The standard steps for this process are depicted in Fig. 3.
- *Register new DID:* Users create a new identity on the digital verse. For example, the public-private key pair is created on blockchain, that is the DID. The user registers this new DID to the system together with their PID. Then, the system verifies whether the registered DID is valid or not. If it is valid, the system creates a new mapping for PID to DID. If it is not valid, the registration is rejected. The standard steps are depicted in Fig. 4.

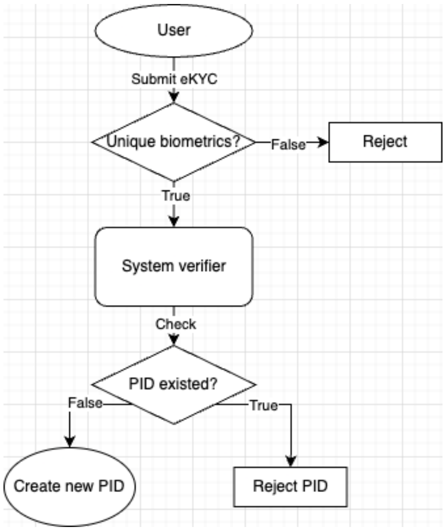

Fig. 3: *Create new PID*

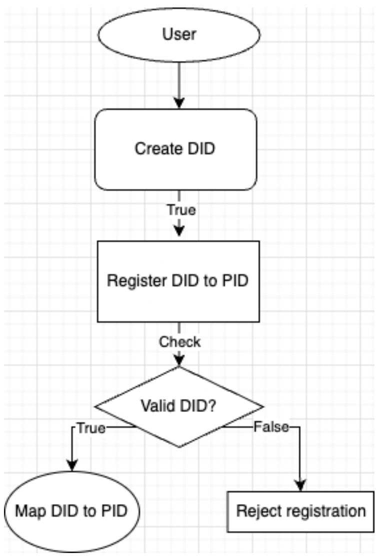

Fig. 4: *Register new DID*

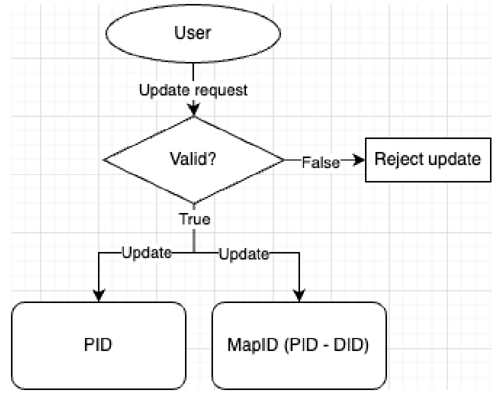

Fig. 5: *Update PID*

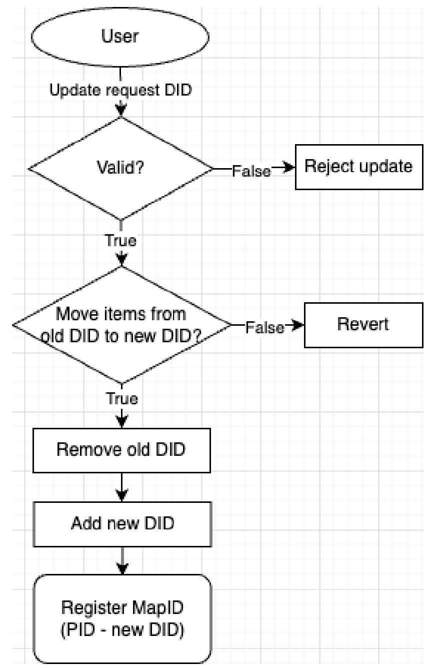

Fig. 6: *Update DID*

- *Update PID:* Users request an update on their PID with new information. And the system will verify if the request is valid or not. If it is valid, the system will update both the PID and the MapID that links the PID. In the other case of and invalid request, the system will reject the update action. Please note that updating PID is only allowed for mutable fields. An update request on immutable (required) fields such as pid or biometrics information, etc. will always be rejected. Updating PID mutable fields does not affect the DID and all of its dependencies. Fig. 5 summarizes the process.
- *Update DID:* Users request an update on their DID. Then the system will verify if the request is valid or not. If it is valid, the system will move all items from the old DID to the new DID. If this moving step is failed, the process is reverted. Otherwise, the old DID from the MapID will be removed, and the new DID will be added as replacement. If the request is invalid, the system will reject the update request. If the old DID is lost (i.e., private key is lost), then the DID is deemed invalid, and all items under the old DID are lost. In that case, we have to register a new DID to the MapID. We make this action clear in Fig. 6.

Summary:

In this whitepaper, the DID is equivalent to the wallet address with public and private key stored in the Layer-1 blockchain infrastructure in the previous section. The DID could be accessible through the blockchain wallet or explorer in the previous section. And DID could also be managed by a web5 solution [7] where they let the users login with user/password credentials and maintained the private key for them. There are several techniques that can provide PID information such as eKYC. Those information for PID are stored off-chain and require proper security to protect the privacy information.

3.3.2. Item Pillar: The item pillar focuses on bringing physical items into the digital realm by facilitating the creation and control of digital assets. By transforming physical items into

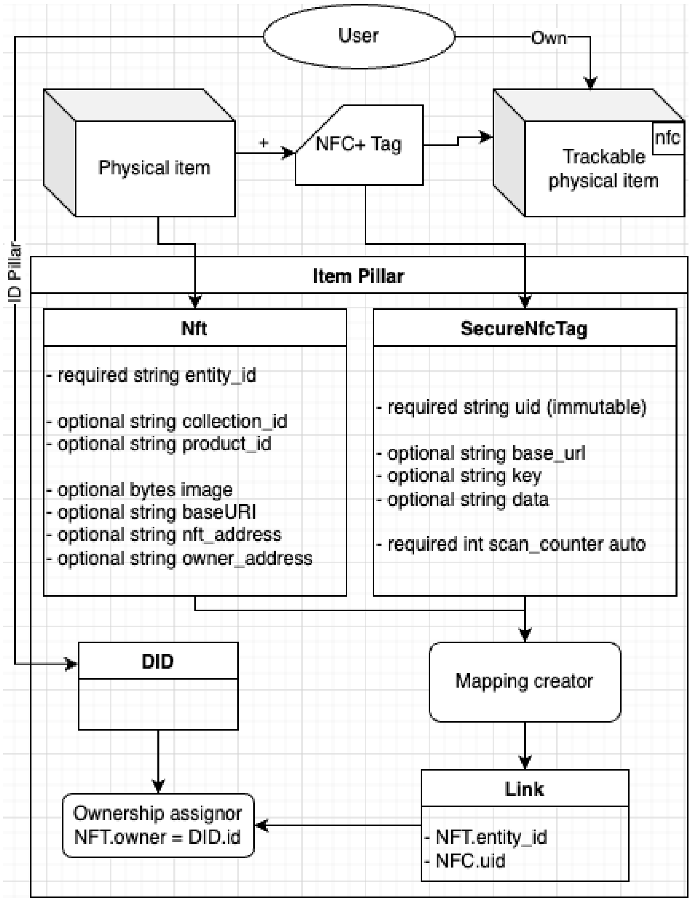

Fig. 7: *Standard process of Items Pillar*

digital versions, various opportunities arise for customization, personalization, and innovative forms of virtual commerce and advertising. This enables the market for digital representations of physical items and facilitates the transfer of ownership.

Requirements:

- Each physical item will have an exact and unique representation on the digital world. This digital representation acts as the fingerprint or receipt of the physical item. The link between the physical item and the digital version is immutable and transparent to the public.
- Another important feature is the ownership of the item. Each physical item and its digital version belongs to an owner, described in the Identity pillar. The owner of the physical item and digital version must be the same at any point in time.
- Any change of ownership in the physical items must be reflected on the digital version, and vice versa. In another word, the change of ownership can only happen when the current owner possesses the physical item and scans the physical to approve the transfer, then the digital version ownership can be changed. The digital version can never be transferred without signature from the current owner and the physical item.

Process:

a) Create trackable physical items: To make physical items trackable, the first step involves equipping them with accessories like QR codes, barcodes, NFC chips, and other tracking mechanisms. There are different pros and cons on each of those aforementioned types so depending on certain types of items and the use cases, we will choose differently. The three criteria to look into are: security, durability, and cost. In the Table I below, we present those criteria for QR code, NFC, and NFC+ with their use cases and examples.
   i) Security: to guarantee the physical item is authentic and unfakeable. One straightforward approach is to incorporate an accessory, such as an NFC tag, into the item to establish its identification. However, a critical challenge arises: ensuring the genuineness of these NFC tags, preventing any potential replacement or counterfeiting. Our solution is secure NFC+ tags, namely NFC+ tag with two important features:
      - Digital signatures to reliably guarantee authenticity. Since the tag itself is not counterfeit, we can guarantee the NFC tag's authenticity using digital signatures that cryptography techniques can provide.
      - Guaranteed authentication process (the message is truly from the NFC+ tag). The Secure Unique NFC function (SUN) generates a unique and secure authentication code whenever the tag is read. Being also connected to the scan counter, each time the tag is read, it generates a different string. In this way, the content is protected from cloning.
   ii) Durability: The QR code is known to have limited lifespan. Its durability depends on the surfaces it is printed on as well as the surrounding environment. Meanwhile, NFC tags can endure several years when embedded in protected materials such as plastic cards or stickers.
   iii) Cost: the cost for QR codes is relatively low. In fact, there are many free QR code generators available online. Printing QR codes on papers, plastics is also inexpensive. NFC technology is more costly. The price of NFC can range from a few cents to one or several dollars, depending on the type of NFC and its memory capacity.

b) Create a digital version for the trackable item: The output of this step is a non-fungible token (NFT) with a unique ID and its address on the blockchain. NFTs are unique cryptographic tokens on the blockchain representing ownership of digital or real-world items. They are distinct and cannot be duplicated.
   For each NFC+ tag attached to the physical item, one NFT will be created through our NFT creation platform by providing all necessary information:
   - Entity ID - unique id for this item.
   - Collection ID - if there is a collection that it belongs to.
   - Image - the display image for this item.
   - Other optional data such as the NFT address -

TABLE I: Comparison for QR code, NFC, and NFC+

Criteria	**QR code**	**NFC**	**NFC+**
Security	Easy to counterfeit Easy to unauthenticate	Hard to counterfeit Easy to unauthenticate	Protect against counterfeit and authentication
Durability	Short lived Surface easily degraded	High 10 years lifespan 100,000 read/write	High 10 years lifespan 100,000 read/write
Cost	<1c	1c-1$	1$+/chip
Use cases	Consumable, short-lived products	Commodity goods	Luxury, limited edition

the address on blockchain which resides this item, manufacturer, etc.

c) Link the trackable items to the digital version: To link a trackable item (with NFC+ tag) to its NFT digital version, we store the mapping record on a smart contract on blockchain, to keep it transparent and immutable. Technically, the system creates a mapping between $NFC.uid$ to $NFT.entity_id$.
Note that the association is the 1-on-1 mapping between the NFC+ tag with the NFT on blockchain. Therefore, each NFC+ tag represents the physical item. We need to ensure the NFC+ tag can not be removed or detached from the physical items to avoid counterfeit issues.

d) Assign ownership of the item on both verses: In our real world, physical items in real life do not alway have clear ownership recorded. With phygital items, the ownership can be assigned and verified easily using blockchain technology. The process is as follow:
   - Find the digital ID (DID) of the owner of the physical item
   - Assign this DID to be the owner of the NFT digital version: Nft.owner = this.DID.id
   - From this point on, only the owner of this NFT can manage both the physical and the digital version of the item.

It is worth to note that the combination of NFC tag, mobile device, backend server, and smart contract on blockchain allows NFC+ tags to achieve two most critical features: self-identification and owner-identification. This is significant because the change of ownership would now require the approval from both the owner and the item. The process is as follow (Fig. 8):
   - The owner scans the item and asks for “change of ownership”.
   - The item verified if this is the true owner. If it is valid, the item approved the “change of owner” request. If it is invalid, the item rejects the request.
   - The physical item is updated with the new owner. Now only the new owner can trigger a request to the item.

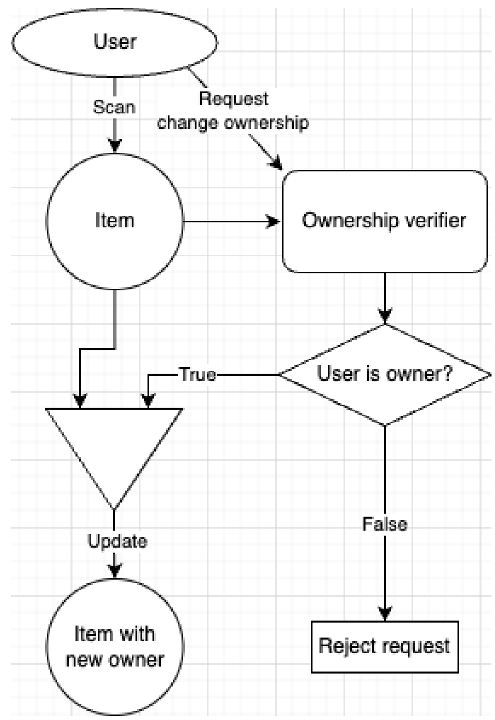

Fig. 8: *Change of ownership*

3.3.3. Location Pillar: The location pillar transforms a real-world location into a location in the metaverse by creating a virtually digital representation of a physical space. The concept of metaverse does not make any limitations on the imagination of builders or creators for making the virtual environment more immersive. This may open the potential for new revenue business models of virtual commerce and advertising. Various technologies can be used such as AR/VR, 3D modeling applications, and other interactive elements. And users could see an opportunity to have a unique and engaging experience that has never been possible in real life.

Requirements:

Real location must be able to detect phygital IDs or items when they are in range and allow checking-in/out automatically. In the digital space, a metaverse location must have a digital address (web address) and be accessible through web browsers or special applications. The metaverse location must maintain the key characteristics of the real-world location, i.e. differentiating one metaverse location from another. Checking in through metaverse location or physical location must be recorded.

Process:

a) Transform physical location to phygital location: A phygital location is a location that can have self-identity, can detect nearby phygital items or phygital people, and allow phygital objects to check-in/check-out automatically or manually. In order to achieve the aforementioned requirements, the physical location needs to be equipped with tracking devices. We can install a positioning device in the real location so it can track bluetooth signals. The device should have low power consumption,

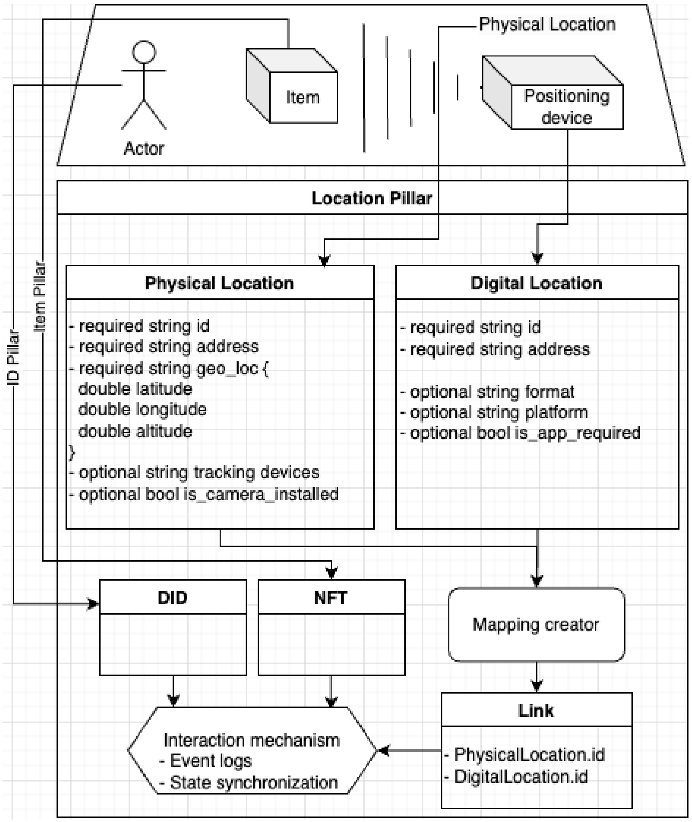

Fig. 9: *Standard process of Location Pillar*

and can keep broadcasting its UUID (Universal Unique Identity) via a tracking technology. There are a few options to achieve this: Bluetooth tracking devices, wifi tracking devices, QR Code. We compare their pros and cons in Table II below.
The physical location can also be equipped with other high-tech devices such as camera, recorder, alarm etc. A complete blueprint of the phygital location and its associated allowed actions must be provided and programmed to enable seamless and complex interaction with the digital space if needed.

b) Create a digital version of the real location:
A digital version of a real location must maintain its key characteristics and have a digital address for accessibility. Different formats can be used to express a location digitally, including text-based descriptions, 2D/2.5D maps with typical image format jpg or png, 3D models, and more. Each format has its advantages and limitations, but the main goal is to differentiate one location from another, either through accurate mapping or notable features.
The most common format for creating a digital version of a location is 3D, which is widely used in metaverse platforms like Decentraland and Sandbox. There are two approaches to creating a 3D version. The first approach is to build individual 3D models from scratch, which can be time-consuming but results in the most accurate representation of the real-world location. The second approach involves using LiDAR technology to scan and capture models of the real-world location. While this approach is more flexible, the output may be less accurate compared to the first approach. The choice of method depends on the specific context and requirements.
After creating the digital location, the next step is to select a platform for its expression and assign a unique digital address within the metaverse. Popular metaverse platforms for uploading digital locations include Sandbox, Decentraland, Roblox, and Spatial. When choosing a platform, several criteria should be considered:
- Price: Some platforms allow free uploads, while others require subscriptions or land ownership. The cost of obtaining land can vary depending on the platform and location.
- Features: Platforms may cater to general purposes or offer specialized features for different use cases, such as voice chat, group chat, or special effects. Certain platforms may be better suited for specific needs.
- Supported formats: Some platforms have strict requirements for the types of formats that can be uploaded, posing a challenge for creators of general 3D objects.
- Ease of access: Some platforms provide dedicated applications for accessing digital locations, while others allow access through standard web browsers.
- API connectivity: Certain platforms offer public API connectivity, enabling developers to program and create more complex interactions within the digital space, while others have restrictions on programmability.

Considering these factors will help in selecting a platform that aligns with specific requirements for expressing the digital location effectively. Regardless of what platforms are chosen, they will create a unique digital address for the digital version. That unique address will be the ID of the digital version and be used to access the location through either the app or web browser.

c) Link the physical location and the metaverse location:
To link the physical location address and the metaverse location address, we create a mapping in a smart contract and store it in the blockchain. The system creates a map entry for PhysicalLocation.id and DigitalLocation.id

d) Enable interactions for phygital objects on both phygital location and metaverse location:
One basic feature of the phygital locations is that they allow phygital items and people to check in automatically when they are in-range. For example, when a phygital item moves within range of a phygital location, the system will do the following steps:
- An event is automatically recorded in the location logs.
- A notification is sent to whatever applications or tools associated with the items or owner of the items.
- The item owner can then ignore, reject, or accept

TABLE II: Comparison for Bluetooth, Wifi, and QR code

Positioning device	Pros	Cons
Bluetooth	Short-range tracking(30 meters or less) Low power consumption Operate within a network of devices without needing Internet connection Provide precise location tracking in real-time	Requires Bluetooth to be turned on permanently Only track devices that have a Bluetooth signal Limited range, less effective over large distances.
Wifi	Wide tracking range, effective for tracking over medium to large distances Works well in areas or public spaces with strong WiFi signals Provides more accurate location tracking than Bluetooth	High power consumption, requires recharge in a short amount of time Requires Internet connection to function and only track devices connected to the Internet Interference from other WiFi networks can affect performance and accuracy
QR Code	Easy to use and cost-effective High adaptability A simple and secure method for tracking data and redirecting to a predetermined destination Can store considerable amounts of information	Requires physical interaction with the code to track data Can be easily damaged or obscured Limited tracking range Mostly requires Internet connection to access information

the notification to publish it to other channels if they want to.

Note that while each interaction event is logged automatically and transparently to the public, it is cryptographically encrypted to protect the anonymity of the phygital items and people so that the public can not be able to identify them without permission of the owners. Checking-in the digital location could also trigger a check-in on the physical location. For example, when an identified digital ID or item enters the range of a digital location or triggers some predefined action like pressing a button or checking-in, that could result in:

- An event is recorded in the location logs.
- The associated phygital location receives a notification to take action.
- The associated phygital location can trigger other actions like allowing the digital ID to enter, or to turn on the camera to show the inside of the physical location, etc.
- The digital ID person can now interact with the phygital location or people in there.

Depending on the configuration of each phygital location, interactions or activities between different phygital items and people in the phygital location could also be recorded and trigger a series of other actions. For example, a change of ownership in one phygital items can be initiated in a phygital location:

- A transfer of ownership request is initiated to the phygital item.
- The item checks if it is within a phygital location and whether the location supports this action.
- If the action is supported, the phygital location records the event in its log.
- The rest of the transfer of ownership process happens and finishes.
- The phygital location updates the new ownership and sends the new notification to all the participants to trigger a new series of actions if needed.

Similar actions could be supported in the digital space as well if configured.

3.3.4. Activity Pillar: The activity pillar transforms any activity in real life to a digital world by simulating the activity in a virtual environment and allows users to participate in. This can be done using a combination of various technologies, such as virtual reality, augmented reality, and gamification. Gamification techniques can make the virtual activity more engaging such as adding rewards, challenges, and social interaction to the virtual environment.

Requirements:

- Activity in the real world must be trackable in some known forms in order to be presented in the digital world. For instance, a runner's exercise can be logged with a GPX tracklog, including details like time, distance, and calories burned. Similarly, a biker's race participation can be recorded with a GPX tracklog and race metadata, such as event date and organizer information. Golfers can also record their tournament participation, including hole achievements for each hole and tournament details. These records are intended to be public and verifiable.
- Activity must be tracked in real-time, or with timestamp, to reflect the time dimension. For example, if activities can not send heartbeat in real-time to check-in, it must store the activity data offline with timestamps recorded to dump these data later.

Process:

a) Track activities in real world to create the phygital activity data: In order to generate phygital activity data, it is necessary to track real-world activities. The most common action is tracking movement from one point to another, which can be achieved through various activities like running, swimming, walking, and biking. Popular applications such as Strava and Fitness, as well as devices like Garmin, Fitbit, and Apple Watch, can accurately track these movements. Tracking methods can involve Bluetooth, GPS, or internet connectivity for real-time reporting. In cases where real-time monitoring is not possible, offline tracking with timestamps can be used to record and report activities later.
Advanced tracking methods can capture additional details such as heart rate, speed, acceleration, and path shape, providing more insight into movement activi-

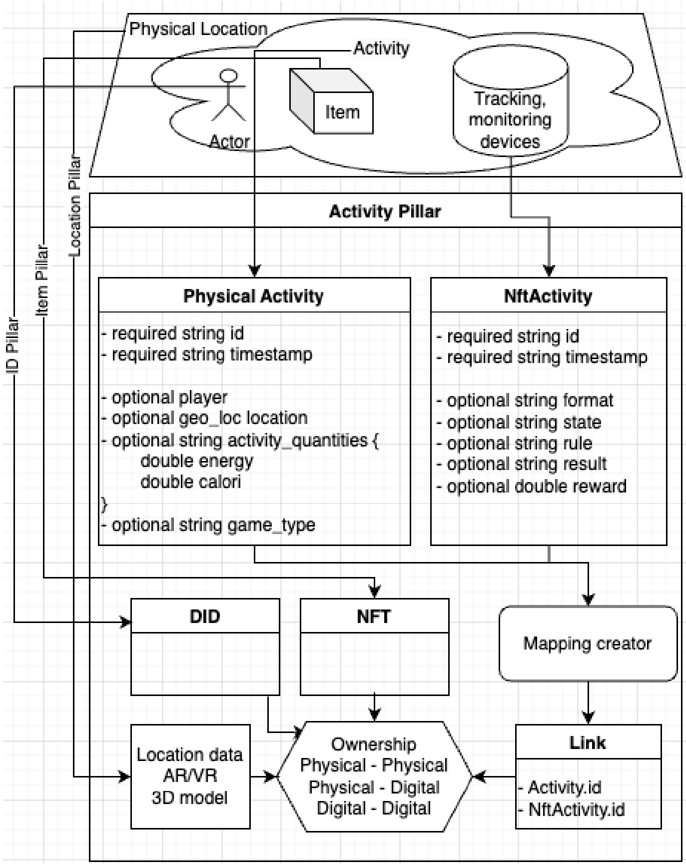

Fig. 10: *Standard process of Activity Pillar*

ties. The activity pillar adds a temporal dimension to the previously discussed pillars. By combining location tracking, check-ins, and rudimentary activity data, a comprehensive picture of user behavior in the real world can be reflected in the digital realm.

Non-movement actions like reading, cooking, and sleeping, although less common, can also be tracked using specialized applications or hardware, contributing to a better understanding of user behavior in the digital space.

b) Convert phygital activity data to digital format: Similar to the item pillar, we use NFT as a digital format to store phygital activity data. Each NFT could represent the phygital activity from overview to detailed level. For movement action, the NFT format should contain all necessary information such as start and end location, total distance traveled, total time traveled, average speed etc. to more detailed information such as total calories burnt, average heart rate etc. Most importantly, the NFT must reflect the unique image to represent this particular activity. The most common way to represent this image is drawing the exact path traveled from point A to point B, as recorded from the tracking applications or devices. Even for many people traveling the same route, the exact mapping for each person will be different, hence yielding the uniqueness of the image for this NFT. Lastly, NFT should also show the owner of this action, which is the digital ID or wallet address of the person who did this action.

c) Link the real world activity to the digital world: To establish a connection between real-world activities and their corresponding digital counterparts, known as the action NFTs, a mapping is created in a smart contract and stored on the blockchain. This mapping involves creating an entry that links the Activity ID with the NftActivity ID. By storing this information on the blockchain, the relationship between real-world activities and their associated digital representations is securely established and can be accessed as needed.

d) Enable interaction: Interactions in the phygital context involve communication and reactions between people and things. These interactions can be categorized into three types:
   - *Physical - Physical:* In the physical world, people interact with each other through activities like joining races or attending events. In the digital realm, their digital identities mirror these interactions, allowing them to virtually run together or form connections.
   - *Physical - Digital:* People can also interact with the digital identities of others. For instance, in a phygital marathon, runners' location data is streamed and visualized in the virtual race. Viewers can support runners by interacting with their digital identities through actions like sending cheers or applause. These digital interactions can be translated into physical experiences, such as hearing fireworks sounds or feeling vibrations on the runner's device.
   - *Digital - Digital:* Digital identities naturally interact with each other in appropriate contexts. In the phygital marathon example, digital identities participating in the virtual race are ranked against each other. As one runner overtakes another, the rankings change, creating an interaction between the two digital identities. These digital interactions can be translated into physical signals, such as device vibrations, to bridge the gap between the digital and physical worlds.

   Overall, interactions in the phygital realm encompass a combination of physical and digital elements, enhancing the overall user experience and merging the boundaries between the real and virtual worlds.

3.4. Digital Grand Park (DGP) and Beyond

The ultimate objective of the P.I.L.A. transformation is to seamlessly integrate physical lifeforms into the digital realm. To achieve this, a diverse range of activities is necessary to sustain life in the digital world, including socializing, item exchange, and entertainment. We have named this space the Digital Grand Park, a name that encapsulates the grandeur and sophistication of our vision for an advanced and comprehensive metaverse infrastructure. The inclusion of the word ”digital” emphasizes the project's technology-driven nature, while ”grand” conveys a sense of scale and ambition. The addition of ”park” infuses the name with liveliness and accessibility, fostering a welcoming and inclusive environment for users. Overall, Digital Grand Park effectively communicates the project’s purpose and values. The various activities within DGP rely on essential infrastructures such as AR/VR integration, gamification elements, an item marketplace, and a viewership platform.

3.4.1. AR/VR Integration: To fully embrace the potential of the metaverse, DGP must incorporate AR/VR integrations. This means creating an immersive virtual environment that supports popular AR/VR devices such as the Oculus and HTC Vive. To enhance user experience, the virtual environment must also support spatial audio and realistic physics.

Spatial audio is a crucial feature for AR/VR experiences as it provides users with a sense of immersion by simulating sound in 3D space. This allows users to perceive sound coming from different directions and distances, creating a more realistic and engaging experience. Realistic physics, on the other hand, is essential to create a sense of presence and physical interaction within the virtual environment. Furthermore, AR/VR integrations open up new possibilities for DGP, such as virtual tours of physical locations, virtual product demonstrations, and interactive experiences. To achieve this, strong partnerships with existing players in the AR/VR ecosystem are key. The DGP can also explore collaborations with AR/VR content creators to bring unique and engaging experiences to its users.

In summary, AR/VR integrations are crucial for the DGP to fully embrace the potential of the metaverse. By supporting popular AR/VR devices and creating a virtual environment with spatial audio and realistic physics, the DGP can provide an immersive and engaging experience for its users.

3.4.2. Gamifications: The DGP is not just a portal for onboarding the physical world onto the metaverse, it is also a platform for virtual engagement and experiences. Gamification is an important part of this engagement, providing users with rewards and incentives to participate and contribute to the metaverse.

The requirements for gamification in DGP include a scalable system to accommodate large numbers of users and activities, a reward system that incentivizes participation and contribution, and a seamless integration with the broader DGP platform. To meet these requirements, various gamification implementations have emerged in the blockchain space, such as Defi Kingdom, Layer3, and Philand. These implementations use a variety of mechanisms, such as non-fungible tokens (NFTs), digital assets, and virtual land ownership to incentivize and reward users.

For example, Defi Kingdom is a game that allows users to build and manage a virtual kingdom using blockchain-based assets. The game’s assets are NFTs that can be traded and used in other games and platforms, providing users with real value for their contributions to the game. Similarly, Layer3 is a platform that allows users to create and share virtual experiences using NFTs as virtual tickets, providing an incentive for users to create engaging experiences that others will want to participate in.

These gamification implementations demonstrate the potential for the DGP marketplace to incorporate similar mechanisms to incentivize and reward users for their contributions. By integrating a reward system that uses NFTs or other digital assets, the DGP marketplace can incentivize users to participate in virtual experiences, such as digital fashion shows or virtual marathons. Additionally, by integrating with fiat and crypto payment systems, the DGP marketplace can provide a seamless experience for users to purchase and sell virtual goods, and even enable physical shipping of these goods.

In closing, gamification is a crucial aspect of the Digital Grand Park, providing users with rewards and incentives to participate and contribute to the metaverse. By leveraging the mechanisms developed in the blockchain space, such as NFTs and digital assets, the DGP marketplace can incentivize users to participate in virtual experiences and contribute to the growth of the metaverse.

3.4.3. The Marketplace: The DGP needs to have an NFT marketplace where users can buy, sell, and trade digital assets. The marketplace should have features such as escrow services, bidding options, and low transaction fees.

The marketplace needs to accommodate a large number of items, from in-game items to NFTs. It also needs to support both fiat and crypto payment options to ensure accessibility and flexibility for users. Additionally, a physical shipping feature is required to bridge the gap between the digital and physical world, allowing users to receive their purchased items in the real world.

To implement the marketplace, we can leverage existing solutions such as OpenSea or develop a custom solution tailored to its specific requirements. OpenSea is a popular NFT marketplace that supports both Ethereum and Polygon networks, providing a wide range of features and integrations. However, our custom marketplace such as Agoran can provide greater flexibility and control over the marketplace’s functionality and user experience. Integrating with established payment providers such as PayPal or Stripe can offer a familiar and convenient payment experience for users. Integrating with logistics providers such as UPS or FedEx can facilitate the physical shipping of items. Ensuring the security and privacy of user data and transactions is also crucial, and can be achieved through various measures, such as implementing SSL/TLS encryption and using secure wallets for crypto payments.

Overall, the marketplace within DGP plays a vital role in enabling commerce within the metaverse and connecting the digital and physical worlds. By carefully considering the requirements and implementing the appropriate solutions, we can provide a seamless and secure marketplace experience for its users.

3.4.4. The viewership platform: A platform that showcases activities on the metaverse would be a great addition to the Digital Grand Park. The platform should allow users to watch and interact with live events and recorded content from various virtual worlds. To accomplish this, we can create a platform that aggregates content from various virtual worlds and presents it in an organized and user-friendly way. The platform could also have social features, such as chat and commenting, to enable interaction and community building among users.

In terms of technical implementation, we can leverage existing video streaming technologies such as WebRTC and RTMP to provide low-latency, high-quality video streaming. We can also use blockchain technology to ensure transparency and immutability of the content and transactions on the platform. The viewership platform can also be monetized through various means, such as subscription models, advertising, or transaction fees for buying virtual items showcased in the content. This will not only generate revenue for the platform but also incentivize content creators to produce high-quality and engaging content.

Overall, a viewership platform that showcases activities on the metaverse would be a valuable addition to the Digital Grand Park. It would provide a central hub for users to watch and interact with live events and recorded content from various virtual worlds, while also offering monetization opportunities for the platform and content creators.

IV. Conclusion

Our proposed comprehensive solution presents an exciting opportunity to bridge the gap between the physical and digital worlds. By establishing a standard process for integrating key components of real life into the digital verse, namely People, Items, Locations, and Activities, we unlock a multitude of benefits ranging from improved accessibility to enhanced scalability and engaging experiences. To bring this vision to life, we are actively leveraging emerging technologies such as VR/AR, NFC+, 3D modeling, and blockchain infrastructure. Blockchain, in particular, offers the inherent advantages of transparent ownership records and trustworthiness, which will facilitate the development of a new exchange market and economic activities in both realms. While our approach is ambitious, we are committed to turning theory into practice. Through a combination of ongoing research, development, and collaboration, we are steadily progressing on our roadmap toward realizing this convergence. We anticipate that within the next decade, an increasing number of ideas and actions will contribute to the mass adoption of this transformative scenario. By converging the physical and digital worlds, we have the potential to reshape society, revolutionize industries, and unlock new realms of human potential. With each step forward, we move closer to a future where the boundaries between the physical and digital realms blur, enabling us to create immersive, interconnected, and inclusive experiences for all.

References

[1] Ballina, Francisco Javier, et al.“The Phygital Experience in the Smart Tourism Destination.” *International Journal of Tourism Cities*, vol. 5, no. 4, 2019, pp. 656–671,https://doi.org/10.1108/ijtc-11-2018-0088.

[2] Banik, Shanta. “Exploring the Involvement-Patronage Link in the Phygital Retail Experiences.” Journal of Retailing and Consumer Services, vol. 63, 2021, p. 102739, https://doi.org/10.1016/j.jretconser.2021.102739.

[3] Batat, Wided. “Experiential Setting Design.” *The New Luxury Experience*, 2019, pp. 113–139, https://doi.org/10.1007/978-3-030-01671-5_6.

[4] Lutz, Sander. “Yuga Labs Joins Gucci to Announce Otherside-Themed Jewelry.” Decrypt, 4 Apr. 2023, [Online]. Available: https://decrypt.co/125360/yuga-labs-joins-gucci-to-announce-otherside-themed-jewelry.

[5] S. Nakamoto, “Bitcoin: A peer-to-peer electronic cash system,” 2008 [Online]. Available: http://bitcoin.org/bitcoin.pdf.

[6] Nguyen, H. et al.,”KardiaChain - The First Decentralized Interoperable and Self-Optimised Blockchain Ecosystem”, Kardiachain. Accessed 16 May 2023. Available:https://dl.kardiachain.io/paper.pdf.

[7] Dorsey, J. (@TBD54566975). “Web5: An Extra Decentralized Web”. Twitter, 10 June 2022,https://twitter.com/TBD54566975/status/1535303403361824768.