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Blockchain-based Governance, Risk Management, and Compliance for Fractional Ownership: Design and Implementation of A Decentralized Autonomous Agent System

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Abstract

Fractional ownership makes homeownership more affordable. But there are challenges in a fractional ownership real estate transaction (FORET) regarding governance, risk management and compliance (GRC) processes. Centralized GRC solutions are less effective in managing the tiered structure of communications in a FORET, which can lead to principal-agent problems such as information asymmetry, risk aversion, and moral hazard. In this research we investigate how these principal-agent problems in FORET could be mitigated. Using an agency theory perspective, we adopt a design science multimethodological research approach. We propose conceptual and system artefacts to support the design and implementation of a decentralized autonomous agent system. These artefacts deliver a formal problem representation structure related to centralized GRC in fractional ownership. We illustrate our solution with a system prototype and implementation. We evaluate the research outputs and compare them with existing GRC systems. This paper contributes to the understanding of GRC in supporting fractional ownership decision making.

Keywords: Blockchain, governance, risk management, compliance, fractional ownership.

1. Introduction

The sharing economy has produced favorable market conditions for fractional ownership (Puschmann & Alt, 2016). Owning a fraction of a house to participate in homeownership is a growing trend since the housing market has become increasingly unaffordable in developed countries. According to the latest industry report, the number of co-buying houses has significantly increased in the last decade (Attom, 2021). Co-buyers include friends, roommates, partners, and family members who bought a single house with clarifications over ownership portions. From the perspective of real estate agents, the co-buying decision is the outcome, and the tough housing market could create more potential benefits and opportunities than disadvantages (Lowies et al., 2018). Prior research reveals that the dilemma of the fractional homeownership decision is often rooted in the principal-agent problem during the transactional GRC processes (Hoksbergen et al., 2021). Information systems (IS) scholars have identified that the principal-agent problem with ineffective GRC could lead to transaction failure (Moeller, 2011; Wang & Haruvy, 2012). Unresolved conflicts of interest and ineffective GRC solutions thus pose potential threats to real estate market with growing demand of fractional ownership housing.

In this study, we define the fractional ownership real estate transaction (FORET) as the housing transaction for consumers who could not afford to own a house individually but they could purchase a fraction of it with intention to reside. We purposefully distinguish our definition from timeshare properties and vacation houses. We also characterize the unique attribute of FORET as co-buying to reside, and that differentiates our domain of interest from other investment vehicles like real estate investment trust and tokenized asset. At an early stage of a FORET, consumers decide on what fraction of which property to purchase, while agents provide services to support them. From agency theory perspective (Jensen and Meckling, 2019), this is where a principal-agent relationship established, i.e., when an entity (as "agent") is enabled to make decisions, influence, and possibly take actions on behalf of customers (as "principal"). As both agents and consumers are forward looking, the design of GRC mechanisms could have a profound impact on their decisions during the transactional processes (Wang & Haruvy, 2012). In centralized GRC systems, whereby communication structure is hierarchical and multilayered, an agent tends to obtain more information than buyers (Hoksbergen et al., 2021). Hence, the agent may initiate gaming behaviors, such as hiding critical

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information or giving misleading information, for the purpose of utility maximization. For instance, a real estate agent might hide the maintenance issues of common areas (e.g., lawn and garden) of the fractional ownership house in order to get the consumer buy a fraction or a set of fractions of the house. Another example, an agent might sell the same fraction of the house to multiple consumers. In these scenarios, the agent has started gaming behavior, i.e., set up information disclosure strategy to get the highest outcome. On the other hand, consumers (as principals who rely on agents to access information) are rational and could be aware of the agent's gaming behaviors through other communication channels (e.g., personal network and social media). The transaction thus straightforwardly becomes a series of zero-sum games manifested by principal-agent problems such as information asymmetry, risk aversion, and moral hazard. The existence of these games infers that centralized GRC might no longer be effective in managing the tiered structure of ownership and communication in FORET. Motivated by that, we define our research question as followed:

"How could a decentralized GRC solution mitigate the principal-agent problem in FORET?"

Principal-agent problems, such as information asymmetry, risk aversion, and moral hazard in centralized GRC are critical and should be well-addressed. The impact of such problems is considerable. However, existing studies have not been successfully to capture and conceptualize these intangible problems in the design, implementation, and use of information systems. We aim to fulfil this gap. A multimethodological approach such as design science research (DSR) would be a good fit for our objectives. Following the DSR framework, we will be able to present concepts, models, methods, artefacts, applications, and introduce solutions that have not been proposed before. Through which, we contribute to the knowledge base a further understanding of GRC in surmounting centralized governance weaknesses, supporting fractional ownership and associated decision making.

The rest of this paper proceeds as follows. The second section reviews the conceptual foundation of the study, including the agency theory perspective for DSR research, fractional ownership, and GRC. The third section outlines the DSR approach. The fourth section presents our conceptual artefacts. The phases of system development, implementation, evaluation, and discussion are documented individually from the fifth to the eighth sections. The last section summarizes our contributions, limitations, and the future research opportunities.

2. Theoretical foundation

Agency theory has become well-recognised since the study by Jensen and Meckling (2019) concerning problems that can occur in an agency relationship. Several studies have used zero-sum games to analyze the principal-agent problem in the context of transactional assignments. Berne (1968) believes that by studying strategic decisions of players throughout the real estate game, we can discover the concealed motivation. From Berne's (1968) perspective, we identified recent studies that have used games to understand principal-agent problems in real estate transactions. Lulu and Zhi (2013) figure out that the decision-making process in the real estate transaction is an agent-consumer interaction dynamic process. In this process, the ultimate equilibrium is an outcome of the game in which participants adjusted their strategies under certain conditions. Ricks and Egbert (2013) simulate agents that involved in transactional games to prove that simulated agents also can make far more optimal and realistic decisions. Kim et al. (2016) have designed a simulation that replaces human communication between agents and consumers via a card game. To win this game, an agent needs to identify the intentions of another agent and a consumer and show cards that match the assumptions. Kim et al. (2016) believe that because participants' interactions in the market might be influenced by subconscious cognitive decision making processes and gaming behaviors, there may exist a governance component that could influence the principal-agent problem. In the same vein, this paper combines the agency theory perspective with the DSR research guidelines (Hevner et al., 2004) to investigate, analyze, and address the principal-agent problem reflected in zero-sum games between agents and consumers in the fractional ownership domain. The focus of our research is to overcome unproductive or counterproductive games and enhance decision making through GRC of FORET.

2.1. Fractional ownership

Fractional ownership generally engages in multi-perspective views (Worrells et al., 2001). In this paper, to determine the fractional ownership terminology, we consider the polytype of fractional ownership in the context of IS. Since its inauguration, the concept of a fractional ownership program has applied to sharing groups who seek the optimal formation of control rights toward access and benefit from cost-sharing (Eisenmesser, 2019). Derived from the basic concept, fractional ownership nowadays is a way for consumers to meet the affordability of high value goods such as holiday homes, houses, and luxury vehicles that individual ownership is not affordable in general (Hastings et al., 2006). There are fruitful applications of fractional ownership in multiple types of common assets, such as using fractional ownership to support the formation of local communities in managing social housing projects (Arkcoll et al., 2013), providing agricultural infrastructure as a fractional asset that owned by a group of farmers (Pasimeni, 2021), and optimal model for the autonomous vehicle sharing (Takaloo et al., 2021). Alongside technological development, fractional ownership expands to the sharing of intangible assets, including intellectual properties, online access, open software development, and other commons-based peer production such as R&D (Balle & Oliveira, 2018). We summarize the use of fractional ownership in various domains in the fractional ownership taxonomy (Figure 1).

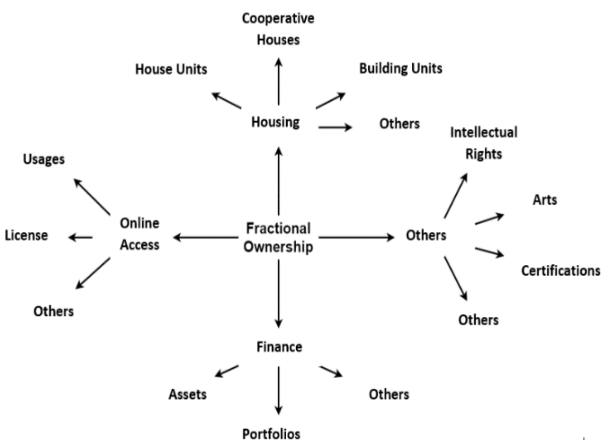

Figure 1. Fractional ownership taxonomy.

The fractional ownership taxonomy enables us to organize the domain where fractional ownership is applicable. We thus can use this taxonomy to index fractional ownership objects classified under online access, finance, housing, and other groups. This will shape fractional ownership as a form of a library classification system that can be included in the design, implementation, and use of information systems. In addition, the taxonomy can give further insights into relationships and principles underlying fractional ownership categorizations. On the other hand, extant research shows a limited number of works on GRC in relation to fractional ownership and associated decision making, which suggests further investigation in this area. Existing literature displays that there is no literature that provides a comprehensive consensus mechanism in the fractional ownership programs, including the respective coordination problems. It raises the question of how to compare these coordinative problems in the fractional owned assets and individual owned ones (Pasimeni, 2021). Lawson (2010) argues that a challenge in generalizing fractional ownership models is the anti-common ownership tendency, which refers to the anxiety feeling of ownership of the favorite products or services only for a limited time. In this paper, we attempt to avoid this problem by the decomposition of ownership periods in monotype of fractional ownership, namely, fractional ownership real estate transactions (FORET). This would support us to clarify FORET as a domain for our research.

2.2. Governance, risk management, and compliance

GRC generally refers to two strands, namely, operational GRC and information technology (IT) GRC. In this paper, we focus on the IT GRC. GRC initially refers to hierarchical management control structures of information (King & Khan, 2012; Green, 2015). From a technology-oriented point of view, IT GRC refers to a technology platform for illuminating governance and compliance risk (Steinberg, 2011; Mahanti, 2021). Researchers have been considering IT GRC as a sub-category of GRC based on the unique role of IT GRC – processes that support IT system operations of an organization (Tarantino, 2008; Cu et al., 2021). It is thus necessary to refer IT GRC to the context of IT platforms that handle primarily issues of information security, IT compliance, IT and data governance, IT risk management, and IT revision (Mahanti, 2021). Hill (2009) emphasizes that there is indeed a need for new strands of studies on the extent to where IT GRC is correctly in place, performs at its best capabilities, and alleviate principal-agent problems such as moral hazards and security violations (Moeller, 2011). Steinberg (2011), Moeller (2011), and Hoksbergen et al. (2021) argue that, instead of helping users to better organize their business operations and support their decision making, centralized IT GRC confuses users with a massive volume of coverage that facilitates information asymmetry, risk performance, and moral hazard. Furthermore, in the hierarchical structure of information management of centralized GRC, when a large number of rules are present, the system is at risk of the single point of failure – when the entire system will stop working because of one part of the system fails. Furthermore, several business units in large organizations have dismissed the moral hazards. They skip priority settings, bypass executive steering committees, withhold critical information, provide misleading information, and take quick decisions with incomplete information.

Several studies have attempted to address these issues by using decentralized technology for the design of GRC solutions. Wang and Kogan (2018) use zero-knowledge proof and homomorphic encryption advantage of blockchain to design a blockchain-based transaction processing system that supports decentralized governance of real-time accounting, continuous monitoring, and fraud prevention. Wang and Kogan (2018) explain that, compared to a centralized ledger, the computational mechanism of blockchain decentralized ledger, such as Merkle tree data structure and Hashing technique, significantly avoid double data recording and improve compliance. This notion has also been enforced by Chong et al. (2019) in the study of comparing five blockchain-based business models. The business models mentioned by Chong et al. (2019) showing advantages of consortium blockchain, smart contract and decentralized organizations (DAO) in terms of governance, business processes automation, and organizational performance improvement. Kim (2020) believes that blockchain with decentralized governance mechanism in tokenized real estate assets can effectively reduce property bubbles. Hoksbergen et al. (2021) argue that centralized GRC facilitates asymmetric information in high value low frequency transactions while blockchain-based solutions significantly improve transactional knowledge management performance. Cu et al. (2021) explain that the principal-agent problem in the fractional ownership transaction such as FORET could be mitigated by DAOs and the immutable, traceable, and irreversible nature of data stored in blockchains. These studies have suggested that blockchain is expected to resolve problems of centralization, inefficiency, and information asymmetry. However, the use of decentralized GRC or decentralized autonomous agents for real estate transaction management such as FORET is largely missing. This missing component has many implications, one specifically is that there is a major gap in understanding between blockchain and GRC solutions supporting decision making in the fractional ownership real estate domain. We aim to portray this gap and we will 1) represent the problems of existing centralized GRC, 2) illuminate the unknown area of GRC and fractional ownership, and 3) bridge blockchain and IT GRC solutions to inform a better and more comprehensive response to address these identified problems.

3. Design science research approach

Design science research (DSR) is a methodology that is motivated by the desire to improve the environment with the introduction of innovative artefacts and the processes for building these artefacts (Hevner et al., 2014). Following DSR phases, we identify and address GRC problems in FORET through the establishment of a new set of conceptual artefacts upon which system artefacts are constructed. The **observation phase** helps us understand the principal-agent problem facilitated by centralized GRC of the fractional ownership transaction. In the **theory building phase**, findings obtained from the observation phase support us to deliver conceptual artefacts that conceptualize, represent, and simplify identified problems to constitute a theoretical ground for the development of system artefacts. In the **system development phase**, we develop a decentralized IT GRC system prototype to address identified problems. In the **evaluation phase**, we follow the framework for evaluating design science research. The research team will carry on further assessments, including system tests and a field study. Following the above DSR phases, we will be able to identify problems, developing conceptual and system artefacts, and obtaining insightful judgments for the artefacts evaluation. The DSR framework thus enables us to address principal-agent problems caused by centralized GRC to support fractional ownership decisions through a formal proposal, design, and implementation of concepts, models, methods, artefacts, applications, and solutions.

4. GRC in fractional ownership: Concepts models and framework

In this section, we discuss our use of theory to support the design of artefacts and define constructs that provide foundations to conceptualize the principal-agent problem facilitated by centralized GRC in the fractional ownership domain. Concepts obtained from the literature review such as fractional ownership, zero-sum games, conflicts of interest, centralized GRC, decentralized GRC, and decentralized autonomous agents have put forward the establishment of the conceptual artefacts such as fractional ownership taxonomy and the FORET participation model (Figure 2).

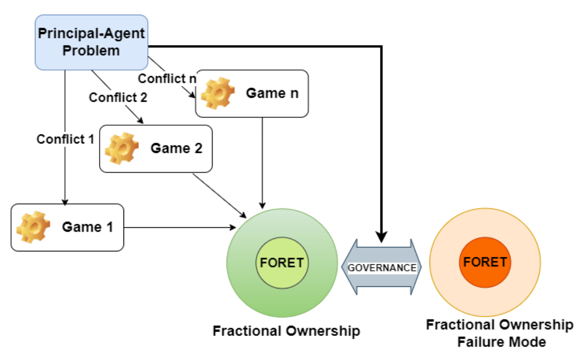

Figure 2. FORET participation model.

Figure 2 illustrates that conflicts of interest rooted in the principal-agent problem are reflected through multiple zero-sum games between consumers and agents. These games generally produce adverse effects on the decisions of stakeholders participating in FORET. In addition, the principal-agent problem occurs because of GRC weaknesses also impacts on FORET. Together, FORET might transform from a successful mode to a failure mode. These interconnections can be captured in the FORET participation model. Another conceptual artefact is the research framework. Following the DSR approach, patterns of conflicts of interest between agents and consumers reflected through zero-sum games in the fractional ownership domain could be addressed in the research framework of this paper. The last type of conceptual artefacts is the information. The obtained information will act as outputs that assist this paper in representing a number of complex patterns of conflicts of interest and governance weaknesses in the fractional ownership domain.

5. Blockchain-based FORET system: Ecosystem, architecture, and components

In the previous section, the conceptual artefacts have put forward the problems of the centralized GRC in fractional ownership. To address these problems, we propose a novel blockchain-based GRC framework built on decentralized autonomous agents (DAA).

5.1. DAA ecosystem

The establishment of the DAA ecosystem is to address the issues of the fractional ownership real estate transaction (FORET) – our working example (Figure 3).

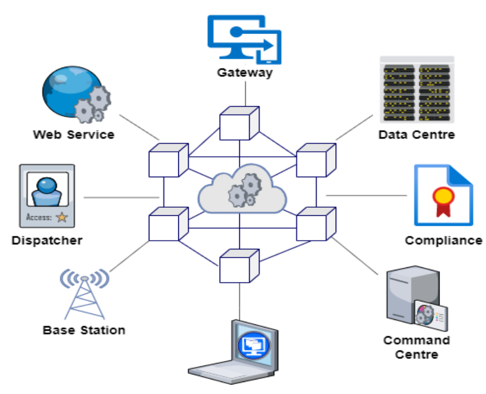

Figure 3. DAA ecosystem.

We believe that a decentralized GRC ecosystem in Figure 3 can mitigate the principal-agent problem facilitated by centralized GRC. The DAA ecosystem with the blockchain cloud backbone directly connects network actors, such as users and dispatchers, to the other network components. Figure 3 shows the absence of human agents in connecting users to other network components, which would reduce intermediate workflows and replicative rules. In the DAA ecosystem, the role of the dispatcher is to support users in operating direct queries. Users will be empowered to authorize DAA deployed in the blockchain cloud to carry on queries and commands. By which, original data sources can be accessed by authorized DAA without concerns of principal-agent problems such as information asymmetry, risk aversion, and moral hazard. Thus, the proposed DAA ecosystem can improve transparency and trust. Notably, the DAA ecosystem will surmount the greatest weakness of centralized GRC – the single point of failure. In a centralized GRC system, if one part of the system fails, the entire system will stop working. In the proposed DAA ecosystem, the single point of failure issue is avoided by an environment that facilitates the independence of system components. When one part of the DAA ecosystem fails, other components remain their functionalities to operate workflows. By avoiding the single point of failure, the DAA ecosystem provides a desirable environment for delivering high availability and reliability business practice and software application.

5.2. Blockchain-based FORET system architecture

In the initial iteration, among available technology, blockchain significantly fits into the decentralized GRC ecosystem in four aspects. First, the shared infrastructure of blockchain networks is well-matched our DAA ecosystem. Second, the noncentral consensus mechanism in blockchain can eliminate repetitive information flows. Third, the non-fungible token (NFT) (a digital currency natives to the blockchain for data encryption) that incorporated Ethereum Request for Comments 20 (ERC-20) (a set of standards that implements an API for tokens within smart contracts in blockchain) effectively encrypt ownership fractions created by the smart contract (so called Fraction.Sol) that is designed to encrypt one NFT ERC-20 per fraction. Finally, the unique hashing technique of blockchain empowers immutability, traceability, and irreversibility of data records. We believe that the blockchain-based GRC system architecture is a good fit for addressing the principal-agent problem facilitated by centralized GRC in the fractional ownership domain (Figure 4). Figure 4 shows the design of the blockchain-based GRC system architecture including (i) user layer, (ii) governance layer, (iii) and database layer. In the user layer, consumers, agents, admin, and other users can access the GRC platform via decentralized apps (dapps) to carry on owner identity verification, ownership certification, peer-to-peer verification, and access the data farm. In the governance layer, we deploy FORET consortium blockchain in the blockchain cloud environment. This consortium blockchain can be integrated into enterprise systems via Ethereum enterprise middleware where we migrate smart contracts. The governance layer will work as a bridge between end users, admin, and the system to create an open governance mechanism, i.e., multiple parties can access and audit the consortium blockchain in real time.

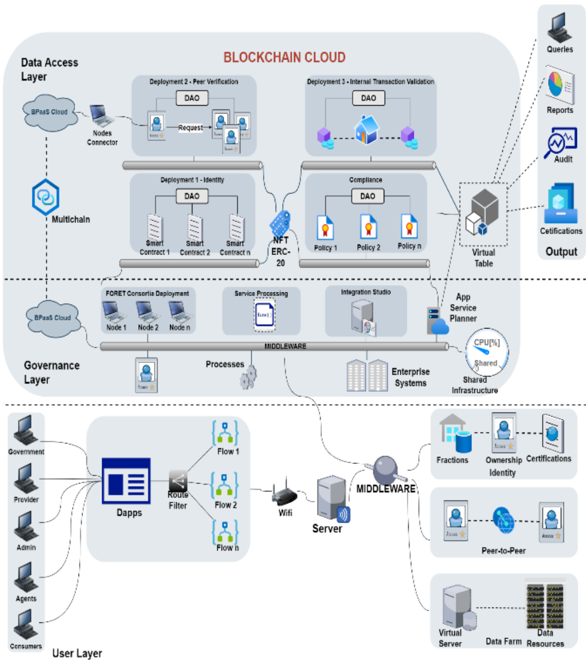

Figure 4. Blockchain-based FORET system architecture.

Figure 4 shows that the admin role in the FORET consortium blockchain might exist alongside blockchain consortium network deployment but also can be absent from regular administrative activities in governance layer and data access layer such as FORET contract creation and approval (Deployment 1 and 2), account balance management (Deployment 3), and recording transactional activities (Compliance). These administrative processes are operated by the decentralized autonomous organization (DAO) and smart contracts deployed to the middleware in the governance layer and will start executing in the data access layer once they are triggered by user's queries via virtual table. In the database layer, there could be an absolute absence of the admin role. For instance, users can directly allow the system approving a request sent by a node. The proposed system architecture thus establishes a semi-decentralized governance mechanism with the reduction of the admin role. In this architecture, we argue that the DAO will play a vital role to address principal-agent problems facilitated by centralized GRC based on several reasons. First, a DAO can replace human agents in multiple governance phases of a FORET such as ownership identity creation, peer-to-peer verification, internal transaction validation, and policy compliance. DAO and associated smart contracts thus can be considered as decentralized autonomous agents programmed to contain the assets and encodes the bylaws. DAO will address the principal-agent problem by reducing both intentional and unintentional human errors in managing data and prevent information asymmetry. Second, DAO acts as the manager of smart contracts that are operated autonomously in decentralized network architecture (DuPont, 2017). A DAO as a manager serves the common interest without taking advantage of information asymmetry can mitigate moral hazard and enhance trust accordingly. By which, DAO transforms the traditional way of governance into a brand-new type of transparent governance, which is the ideal goal of GRC (Beck et al., 2018). Third, because DAO is programmed to be an optimal system, where all policies are primarily defined by program code (DuPont, 2017), which means there is no inefficient centralized control. The Blockchain-based GRC system architecture allows users to carry on activities such as peer-to-peer validations, transactional processes management, and real-time multiparty audit in a radical transparent environment and without a single point of failure in the network. The proposed GRC system architecture based on DAO also takes advantage of blockchain technology such as traceability, immutability, and irreversibility of information, thus can address the identified principal-agent problems facilitated while support FORET participants' decision making.

5.3. Blockchain-based FORET system components

5.3.1. Blockchain cloud platform and FORET consortium blockchain. Consortium blockchain has been proven as an effective and secure network for organizational transaction processing systems (Chong et al.). We have created and deployed a FORET consortium blockchain network run on Hyperledger BESU and SettleMint blockchain cloud infrastructure. The number of FORET consortium members is unlimited. Each member of FORET consortium operates a node and at least two members must approve to create a new block of FORET.

5.3.2. Smart contracts, NFTs, and ERC-20 tokens. In this study, non-fungible tokens (NFTs) are used to represent ownership of house fractions. In blockchain, a smart contract could be considered as a token contract. A popular type of NFTs that has been introduced by Ethereum is the NFT with the Ethereum Request for Comments 20 (ERC-20). This NFT ERC-20 token has a standard for itself, in other words, it has a property that makes each NFT ERC-20 token be the same (in type and value) as another within blockchains. Using contract function of blockchain, we set out the smart contract Fraction.Sol as a NFT ERC-20 contract (Figure 5).

```
/**
 * @FORET owner's shares, ERC20-based token
 */
contract fraction is ERC20Token {
  constructor(
    string memory name,
    uint8 decimals,
    address gateKeeper,
    string memory uiFieldDefinitionsHash
  ) ERC20Token(name, decimals, gateKeeper, uiFieldDefinitionsHash) {}

  bytes32 public constant ADMIN_ROLE = 'EDIT_ROLE';

  function getDecimalsFor(
    bytes memory /*fieldName*/
  ) public view override returns (uint256) {
    return _decimals;
  }
```

Figure 5. FORET's smart contract for ownership identity creation and verification.

Figure 5 shows that the constructor contains code to change and initialize the state variables such as *name*, *decimals* (number of fractions recorded), *gateKeeper* (issuing access), and *uiFieldDefinitionsHash* (hashing defined by data obtained from the user interface). The constructor initiates automatically once the smart contract is created and starts executing in the blockchain. The Fractional.Sol smart contract could define rules (that are similar to a regular contract) and automatically enforce them via the code. The *public constant* keyword for mentioned variables will define their values assigned at compile time and will not allow for any modifications at runtime. Fractional.Sol smart contract thus would not be deleted by default due to all the interactions with them are irreversible.

5.3.3. Decentralized autonomous organizations (DAOs). DAOs are similar to an internet-native business that could be collectively owned and managed by its members. DAOs have built-in treasuries that no one has the authority to access without the approval of the group. Decisions are governed by proposals and voting to ensure everyone in a DAO has a voice (Ethereum, 2022). There are only two entities participating in a DAO, including an executive (company) and members (smart contracts).

6. Implementation of blockchain-based GRC for fractional ownership: A decentralized autonomous agents system

The above system artefacts can be implemented in the real world environment, following the deployment framework in Figure 6. Following the framework in Figure 6, we first created a w3.js site as the prototype of the FORET GRC platform that allows users to interact with FORET consortium blockchain network. The FORET platform consists of multiple automated workflows. Each workflow will drive users to direct access to the blockchain cloud server or database.

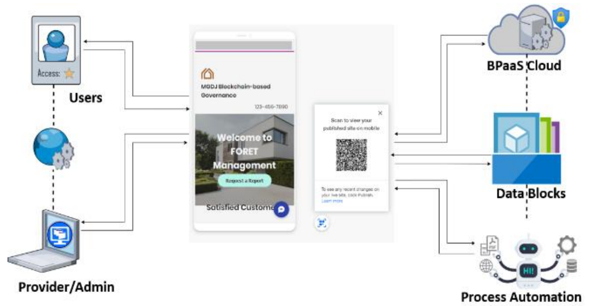

Figure 6. FORET platform deployment framework.

General queries can be automatically handled by web automation solutions by returning queries from data tables connected to the FORET platform. Users could also make other queries on FORET consortia blockchain such as ownership verification, ownership transfers, and requests that enable a specific workflow to create new blocks of information or return queries on existing information blocks. For each workflow, we first customize the respective smart contract and upload them to the cloud library before migrating them to the middleware – the Ethereum blockchain via Enterprise Ethereum integrated development environment (IDE). After the smart contract Fraction.Sol completes its migration, we can use NFT ERC-20 tokens to encrypt FORET's fraction ownership identity. For each transaction input, the mining process includes four key phases, i.e., creating the transaction, sending data to the chain, mining a new block, and updating the backend.

Once we finished the information input, the smart contract Fraction.Sol started operating the process of mining a new block of information – creating a new transaction. The transaction was subsequently sent to the mining nodes of the blockchain to be encrypted as a new information block. There were multiple processes underlying this mining stage including compilation, training, proof of work, verification, and confirmation (Ethereum, 2022). These processes are empowered by blockchain members known as miners who participated in the mining nodes and are invisible to our blockchain consortium network. There were multiple miners collecting on encrypting one transaction after we sent the FORET fractions information to the mining nodes. However, only one miner who could provide the proof of work in the shortest time successfully claimed the reward from the blockchain provider for encrypting the new information block of FORET fractions ownership identity. We also created the workflow of integration off-chain data input to the on-chain smart contract.

We are in the progress of constructing the decentralized autonomous organization (DAO). We will deliver a complete DAO prototype in future research. During the implementation, we have discovered other advantages of using blockchain-based GRC for FORET implementation. First, blockchain computational techniques exceptionally matched with fractional ownership – one encoded block of information per ownership fraction or a set of fractions. The fractions owners thus can effectively manage, verify, and track their ownership identities. The proposed system also provided a friendly user interface. Users could easily carry on queries instead of scraping data from a large centralized system. Second, blockchain-based GRC reduced the power of human agents through which mitigated the games caused by principal-agent problem. Third, traceable and irreversible records in blockchain help alleviate information asymmetry and moral hazard. Fourth, the peer-to-peer verification of blockchain-based GRC helped reduce waiting time for the central admin approval. Finally, the blockchain-based GRC system is immutable due to the unique Merkle tree data structure of blockchain effectively prevents general attacks such as Rainbow table and Dictionary. We believe that the proposed system has established a semi-decentralized GRC mechanism to empower network members, reduce the dependence on human agents, and mitigate principal-agent problems in fractional ownership transactions such as FORET.

7. Evaluation of the blockchain-based FORET system

Evaluation is an essential component of DSR (Hevner et al., 2004). Evaluation methods should be well executed to demonstrate the utility, quality, and efficacy of design artefacts (Hyvärinen et al., 2017) In this section, we will follow evaluation guidelines outlined by Hevner et al. (2004) to assess the proposed artefacts. As the evaluation of designed artefacts requires both evaluation metrics and methods, we propose an evaluation scheme for our designed artefacts including experimental method (study artefacts in controlled and simulated environment), testing (Blackbox and White box), descriptive evaluation (informed argument and scenarios), and observational evaluation (field study). Hevner et al. (2004) argue that the DSR process might start with simplified conceptualizations and representations of problems via the establishment of artefacts. And because the design is inherently an iterative activity, evaluation throughout phases thus provides essential feedback to the construction phase as a way to guarantee the quality of the design process and the design product under development.

In the test environment, we first carried out functional testing (Black Box) to discover failures and identify defects. We then conducted structural testing (White Box) – testing the performance coverage of the integration workflows in the Blockchain-based FORET system implementation. In the initial iteration and testing, the system performed successfully in the following criteria: (i) Blockchain's shared infrastructure well matched the decentralized GRC system architecture. Repetitive information flows were reduced under the consensus in the blockchain. (ii) NFT ERC-20 has successfully encrypted data created by the smart contract Fraction.Sol. In the initial iteration, Fraction.Sol created token contracts verifying fractions ownership identity within < 5s on the shared infrastructure with computing indication 5.13%/3.21 vCPU. (iii) Platform user interface was tested in terms of functionalities for performing workflows and returning reports. Another critical evaluation criteria is in the contribution of this research in the development of novel automation solutions that have not been proposed previously for addressing real world problems and improving business processes. For this criteria, we will use a descriptive evaluation method, i.e., collecting experts' feedback on the proposed systems in future research. For this evaluation method, we will carry out informed arguments with blockchain experts in several areas such as lawyers, software engineers, policy makers, and researchers. As a single iteration of a DSR process also should be evaluated throughout multiple evaluation episodes, in future iterations, we will program the DAO to perform under different detailed scenarios such as replacing human agents in performing queries, mining new data blocks for ownership identity verification, and executing internal transactions validation. The business environment is essential to establish requirements upon which the evaluation of the proposed system is based. Therefore, to demonstrate the proposed system utility, we will develop a full-fledged system using blockchain cloud services and carry on implementation at a field study site (a block of fractionally owned townhouses) in the following iterations.

8. Discussion and limitation

This study evaluates the feasibility of a blockchain-based solution to overcome principal-agent problem in centralized governance, risk management, and compliance (GRC) of the fractional ownership real estate transaction (FORET). As such, we provide a blockchain-based system architecture that enables a decentralized GRC mechanism to mitigate information asymmetry, risk aversion, and moral hazard. We employ decentralizes autonomous agent to replace human agent in multiple phases of the GRC processes.

We have done Black-box testing to examine the functionality of our blockchain-based solution and system prototype. We have also used White-box technique to test internal structures of the solution. Considering the positive testing results, we are confident that the proposed system represents a viable solution to address principal-agent problem of centralized GRC via transparency, traceability, immutability, and decentralized automation. However, our solution might not be considered an entirely decentralized GRC system as it requires traditional banking for payment methods and corresponding compliance of financial institutions. This is, however, a common feature of blockchain-based solutions. Beck et al. (2018) mention that blockchain governance possibly disrupts traditional monetary ecosystems. Nevertheless, there are legal challenges in terms of moving towards absolute decentralized governance. Our proposed solution is limited to a semi-decentralized GRC mechanism in the current real world environment. The solution, however, is visible to mitigate principal-agent problems such as information asymmetry and moral hazard because the information is all published, traceable, and irreversible on the blockchain. Moreover, we will make sure the implementation and use of the GRC platform as convenient as possible for users, thereby reducing concerns on noncompliance issues.

We also consider security issues of blockchain solutions per se. As blockchain is subject to a 51% attack, which is a security threat that occurs when an individual entity holds 51% of the computing power and will be able to claim all transactions of the blockchain. Several scholars discard this concern by referring to the scalability issues or transient inefficiencies of blockchain, which have soon been addressed (Glaser, 2017). In the scope of this study, we would argue that having a blockchain-based GRC solution facilitates the elimination of the principal-agent problem, such as information asymmetry, risk aversion, and moral hazard as discussed in the earlier sections. Regarding blockchain technology and its technological limitations, there is a need for further studies to overcome challenges in future developments. Although the full-fledged system is in the development phase, we deliver a system prototype that demonstrates a feasible solution to reduce the possibility of principal-agent problem when automating a great part of the GRC processes that were previously conducted manually. While the investigated use case is limited to FORET, we assume that adaptive solutions of our prototype could also be useful for avoiding principal-agent problem in GRC processes of high value low frequency transactions such as individual housing, luxury yachts, airplanes, and others.

9. Conclusion

This research embeds blockchain technology to support decision making and address principal-agent problems aggravated by the weaknesses of centralized GRC of FORET. Findings obtained from the observation and theory building phases indicated that the fractional ownership paradigm supported transactional matching assignments. However, fractional ownership transactions contained principal-agent problems rooted in centralized IT GRC. The results of our analysis suggests that strategic decisions of agents and consumers were significantly impacted by information asymmetry, risk aversion, and moral hazard. We have successfully developed a decentralized IT GRC system prototype to address these problems. At the initial system test, blockchain is the well-fitted for our research purposes in terms of technical attributes, network infrastructure, consensus mechanism, data encryption, and data security. The proposed system architecture is expected to mitigate zero-sum games in fractional ownership transactions due to the reduction of human agents' power, information asymmetry, and moral hazard while taking advantage of blockchain technology to improve information transparency, security, trust, and support decision making. The observation results obtained in this research were converted to a set of conceptual artefacts to give further learning on centralized GRC problems in the factional ownership domain, which justifies our theoretical contribution to the knowledge base. In the future iterations, we will carry on full-fledged randomized controlled experiments using computer-based manipulations to evaluate these findings. The evaluation of this paper follows DSR research guidelines to deliver research rigor. We tentatively conclude that the proposed solutions can address principal-agent problems, mitigate conflicts of interest, support fractional homeownership affordability, and are generalizable to a broader area of fractional ownership of high value assets among different stakeholders.

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