ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

STRUCTURAL REVIEW AND PERFORMANCE EVALUATION OF REAL ESTATE TOKENS

M.Sc. THESIS

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Department of Real Estate Development

Real Estate Development Programme

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

GAYRİMENKUL TOKENLERİNİN YAPISAL İNCELEMESİ VE PERFORMANS DEĞERLENDİRMESİ

YÜKSEK LİSANS TEZİ

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Berke Bayhoca, a M.Sc. student of İTU Graduate School student ID 516211001 successfully defended the thesis/dissertation entitled "STRUCTURAL REVIEW AND PERFORMANCE EVALUATION OF REAL ESTATE TOKENS", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my lovely family,

FOREWORD

I am proud to graduate from Istanbul Technical University on the 101st anniversary of the Republic of Türkiye and happy to have completed my thesis. I would like to thank my supervisors Assoc. Prof. Kerem Yavuz ARSLANLI and Assoc. Prof. Bertram STEININGER, for their valuable comments and contributions to me within the scope of this thesis. I also convey my love to my family who has always supported me throughout my academic life, to my nephew Mete Bayhoca and I wish them to read this thesis proudly.

May 2024 Berke BAYHOCA

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ABBREVIATIONS

BTC	**:** Bitcoin
CAPM	**:** Capital Asset Pricing Model
DAO	**:** Decentralized Autonomous Organization
DLT	**:** Distributed Ledger Technology
DPI	**:** Decentralized Finance Pulse Index
ETH	**:** Ethereum
EWT	**:** Equally Weighted Price Index
EWTTR	**:** Equally Weighted Total Return Index
ICO	**:** Initial Coin Offering
IMF	**:** International Monetary Fund
IPO	**:** Initial Public Offering
LLC	**:** Limited Liability Company
MWT	**:** Market Weighted Price Index
MWTTR	**:** Market Weighted Total Return Index
PE/VC	**:** Private Equity / Venture Capital
REIT	**:** Real Estate Investment Trust
SPO	**:** Special Purpose Organization
SPV	**:** Special Purpose Vehicle
S&P 500	**:** Standard & Poor's 500 Index
STO	**:** Security Token Offering

SYMBOLS

$\mathbf{K}$	**:** Kurtosis
$\mathbf{N}$	**:** Number of Assets
$\mathbf{P_t}$	**:** Spot Price at Time t
$\mathbf{P_{t-1}}$	**:** Spot Price at Time t-1
$\mathbf{R_{p,t}}$	**:** Portfolio Return
$\mathbf{R_{p,e}}$	**:** Portfolio Excess Return
$\mathbf{R_{m,e,t}}$	**:** Market Excess Return
$\mathbf{R_{p,e,t}}$	**:** Portfolio Excess Return
$\mathbf{R_{p,t}}$	**:** Portfolio Return
$\mathbf{R_{f,t}}$	**:** Risk-free rate
$\mathbf{R_{i,t}}$	**:** Return of Individual Asset
$\mathbf{R_t}$	**:** Return
$\overline{\mathbf{R_p}}$	**:** Arithmetic Portfolio Return
$\overline{\mathbf{R_f}}$	**:** Arithmetic Risk-free Rate
$\overline{\mathbf{R_{m,e}}}$	**:** Arithmetic Market excess Return
$\mathbf{S}$	**:** Skewness
$\mathbf{T}$	**:** Number of Periods
$\mathbf{W_i}$	**:** Weight of Individual Asset
α	**:** Alpha
$\boldsymbol{\beta}$	**:** Beta
$\boldsymbol{S}$	**:** Sharpe Ratio
σ	**:** Volatility
$\sigma_{p,e}$	**:** Volatility of Portfolio Excess Return
$\sigma_{m,e}$	**:** Volatility of Market Excess Return

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STRUCTURAL REVIEW AND PERFORMANCE EVALUATION OF REAL ESTATE TOKENS

SUMMARY

Today, while the digital world is developing rapidly, it is also transforming. Revolutionary technologies are at the center of this transformation. One of these is blockchain technology, which forms the main theme of this thesis. Blockchain technology, which we were introduced to in 2008 with the Bitcoin whitepaper published by a person or group who still maintains their anonymity, has given rise to a new monetary system debate. Monetary systems have been intertwined with social events throughout history. Developing social needs have changed monetary systems and enabled them to adapt and respond to needs. A person or group behind Bitcoin named Satoshi Nakamoto also described the global economic crisis of the period when they published this study as a global disaster and proposed Bitcoin as a new monetary system. Blockchain technology, which came to the fore with Bitcoin, introduced us to the concept of decentralization and the new internet while creating a new monetary system.

The concept of decentralization is considered to have ushered in a new era of the internet. In the first period of the Internet, which we call WEB1, it was possible just to access data digitally. In this period, called the primitive period of the Internet, users only had the ability to view, it was not possible to create content by users. This period, which contained only fixed content, was defined as the read-only web and the internet was used only as a library.

The WEB2 era started in the early 2000s, offered a user-centered, collaborative and participatory environment. In this period, users have become stakeholders who shape the internet environment with all the data, text or images they add to the internet environment. Therefore, a two-way interaction came to light. In this period when all popular social media platforms such as Facebook and YouTube were created, data shared on the internet began to be kept in the database of these private organizations. In this period, when all digital investment platforms, digital wallets and digital payment solutions started to be used in addition to social media, the ability to store data was available only in the relevant centers. Blockchain technology formed the basis of the WEB3 era, which is called the new era of the internet, where the storage, verification and control of all these data are managed without being tied to a single center.

With the transition to the new age of the Internet, the concept of digital ownership has become a subject of debate again. Thanks to blockchain technology, users have gained the ability to control the data on the assets they own, by providing ownership without the need for any central institution. This situation has laid the groundwork for tokenization technology, which can be defined as the creation of digital representations of assets. There is an opportunity for users to store and exchange a digital representation of their deposits, real estate or works of art in their decentralized wallets. These digital representations are developed by various companies as

investment products as well as a storage tool. Real estate assets are also one of the financial assets evaluated in terms of creating a digital representation. Projects are currently being developed in this direction and offered to both corporate and individual investors.

Within the scope of this thesis study, both the process development phase and financial performance of the tokenization of real estate assets are examined. Reasons such as the fact that real estate assets have been considered a non-liquid asset class throughout history, lack of transparency in the market, high investment costs, high-cost brokers, investment being tied to real estate for a long time, high market entry costs and existing bureaucracy obstacles in international investments have made it necessary for the tokenization of real estate assets. creates motivation. The tokens to be created can provide partial ownership of real estate and enable direct transfers without brokers. At the same time, all these transactions made on open blockchains can be viewed transparently by everyone. In this way, real estate investments can be made with small budgets, buyers and sellers can come together without the need for brokers, and international direct investments are possible.

This thesis study includes quantitative and qualitative research on real estate tokens, one of the leading security tokens. While security tokens based on blockchain technology are rapidly becoming widespread as new-age investment products, real estate tokens have long stood out as one of the most popular of these tokens. The underlying reason for this is that the real estate sector is associated with low liquidity and long and expensive transaction processes. Studies in the literature have analyzed the structural structure of real estate tokens and concluded that they will lead to a significant increase in liquidity for the real estate market. Tokenization platforms and real estate market experts believe that tokenization will solve many problems in the traditional market, as the products that will emerge with the tokenization of real estate assets will increase liquidity by removing high entry barriers to the market and create a secondary market where intermediaries are minimized. This technology, which can provide safe access to a wide market in a short time, theoretically means a new platform for both debt and capital increase.

The aim of this study is to analyze the performance of these tokens as investment instruments by examining the financial data of real estate assets tokenized by RealT, one of the leading asset tokenization platforms. In addition, within the scope of the study, the structure of real estate tokens as financial products was examined and their similarities and differences with traditional products were discussed.

In this thesis study, a historical data set covering a 1-year period of 151 real estate tokens tokenized by RealT and traded in the secondary market was used. 139 of these tokenized properties are in Detroit and 12 in Chicago. Four different indices were created based on the data set of tokenized real estate. The first of these indexes is the equal-weighted price index, the second is the market value-weighted price index, the third is the equal-weighted return index, and the fourth is the market value-weighted return index.

For performance measurement of the created tokenized real estate indices; A financial asset pricing model was used together with Sharpe and Sortino ratios, which provide the opportunity to perform risk-based return analysis. The created indices were compared with reference indices and the results were shared. For comparison, house price indices for Chicago and Detroit, where tokenized real estate is located (Chicago

HI, Detroit HI), indices of real estate investment trusts in the USA (S&P 500 REIT), which is a similar investment product, and non-asset-based real estate traded in the decentralized finance market. DeFi Pulse Index (DPI), which is about tokens, was used.

According to preliminary analysis, the index with the highest return relative to risk was the equal weight total return index (EWTTR) for tokenized real estate. The index with the lowest return according to risk was the DeFi Pulse Index (DPI), which focuses on decentralized finance products that are not asset-based. According to the result analysis, all reference indices had negative beta values against the created tokenized real estate indices.

In summary, within the scope of this study, an empirical analysis was made by comparing the financial performance of real estate tokens actively traded in the market with certain reference indices. The empirical result finds that token indices perform positively relative to the crypto market and traditional market indices in the context of risk-adjusted returns. This positive performance can be explained by investors' interest in real estate tokens, a new investment product, and a success of the RealT company, which selected the real estate to be tokenized. However, in order to make a more accurate comparison, it should be underlined that the increase in the number of real estate tokens and the liquidity in the secondary market is important.

GAYRİMENKUL TOKENLERİNİN YAPISAL İNCELEMESİ VE PERFORMANS DEĞERLENDİRMESİ

ÖZET

Günümüzde dijital dünya hızla gelişirken, aynı zamanda dönüşmektedir. Bu dönüşümün merkezinde devrim niteliği taşıyan teknolojiler yer alıyor. Bunlardan biri de bu tezin ana temasını oluşturan blokzincir teknolojisidir. 2008 yılında, halen anonimliğini koruyan bir kişi ya da grup tarafından yayınlanan Bitcoin whitepaper'ı ile tanıştığımız blokzincir teknolojisi, yeni bir parasal sistem tartışması doğurmuştur. Parasal sistemler tarih boyunca toplumsal olaylar ile iç içe olmuştur. Gelişen toplumsal ihtiyaçlar, parasal sistemleri değişimlere uğratmış ve ihtiyaçlara uyum yanıt vermesini sağlamıştır. Bitcoin'in arkasındaki Satoshi Nakamoto takma adlı bir kişi veya grup da yine bu şekilde çalışmayı yayınladıkları dönemki küresel ekonomik krizi bir küresel felaket olarak tanımlamış ve yeni bir parasal sistem olarak Bitcoin önerisinde bulunmuştur. Bitcoin ile gündeme gelen blokzincir teknolojisi ise, yeni bir parasal sistem oluştururken bizi merkeziyetsizlik kavramı ve yeni internet ile tanıştırmıştır.

Merkeziyetsizlik kavramı, internetin yeni bir çağını başlatmış olarak değerlendirilmektedir. 3 farklı döneme ayırdığımız internetin WEB1 olarak adlandırdığımız ilk döneminde veriye dijital olarak erişebilmek mümkün kılındı. İnternetin ilkel dönemi olarak adlandırılan bu dönemde kullanıcılar yalnızca görüntüleme kabiliyetine sahipti, kullanıcılar tarafından içerik oluşturulması mümkün değildi. Yalnızca sabit içeriklerin yer aldığı bu dönem, salt okunur web olarak tanımlanıyordu ve internet yalnızca bir kütüphane gibi kullanılmaktaydı.

2000'lerin başında başlayan WEB2 dönemi; kullanıcı merkezli, işbirlikçi ve katılımcı bir ortam sunmaktaydı. Bu dönemde kullanıcılar, internet ortamına ekledikleri tüm veri, metin veya görseller ile internet ortamını şekillendiren birer paydaş haline geldi. Dolayısıyla çift taraflı bir etkileşim gün yüzüne çıkmış oldu. Facebook, Youtube gibi tüm popüler sosyal medya platformlarının da oluşturulduğu bu dönemde, internet ortamında paylaşılan veriler bu özel kuruluşların veritabanında tutulmaya başlandı. Sosyal medyanın yanı sıra tüm dijital yatırım platformlarının, dijital cüzdanların ve dijital ödeme çözümlerinin de kullanıma sunulmaya başlandığı bu dönemde, verilere dair saklama kabiliyeti yalnızca ilgili merkezlerde bulunuyordu. Blokzincir teknolojisi; tüm bu verilerin saklanmasının, doğrulanmasının ve kontrolünün tek bir merkeze bağlı kalmadan yönetildiği ve internetin yeni dönemi olarak adlandırılan WEB3 döneminin temelini oluşturmaktadır.

İnternetin yeni çağına geçiş ile birlikte dijital sahiplik kavramı yeniden tartışmalara konu olmuştur. Blokzincir teknolojisi sayesinde hiçbir merkezi kuruma ihtiyaç duymadan sahipliğin sağlanabilmesi ile kullanıcılar sahip oldukları varlıklar üzerindeki verileri kontrol edebilme yeteneği kazanmıştır. Bu durum, varlıkların dijital temsillerinin oluşturulması olarak tanımlanabilecek tokenizasyon teknolojisi için zemin oluşturmuştur. Kullanıcılar için, sahip oldukları mevduatlar, gayrimenkuller veya sanat eserlerinin bir dijital temsilini merkeziyetsiz cüzdanlarında saklayabilme ve takas edebilme fırsatı doğmuştur. Bu dijital temsiller, bir saklama aracı olmanın

yanı sıra birer yatırım ürünleri olarak da çeşitli şirketler tarafından geliştirilmektedir. Gayrimenkul varlıkları da, dijital temsili oluşturulması açısından değerlendirilen finansal varlıklardan biridir, halihazırda bu doğrultuda projeler geliştirilmekte ve hem kurumsal hem de bireysel yatırımcılara sunulmaktadır.

Bu tez çalışması kapsamında, gayrimenkul varlıklarının tokenizasyonunun hem süreç geliştirme aşaması hem de finansal performansı incelenmektedir. Gayrimenkul varlıklarının tarih boyunca likid olmayan bir varlık sınıfı olarak değerlendirilmesi, piyasada şeffaflığın sağlanamaması, yüksek yatırım maliyetleri, yüksek masraflı komisyoncular, yatırımın uzun süre gayrimenkule bağlı kalması, pazara giriş maliyetlerinin yüksek olması ve uluslararası yatırımlardaki mevcut bürokrasi engelleri gibi sebepler, gayrimenkul varlıklarının tokenizasyonu için gerekli motivasyonu oluşturmaktadır. Oluşturulacak tokenler, gayrimenkulün parçalı mülkiyetini sağlayabilmekte ve komisyoncular olmadan direkt transferleri mümkün kılabilmektedir. Aynı zamanda, açık blokzincirler üzerinde yapılan tüm bu işlemler şeffaf bir şekilde herkes tarafından görüntülenebilmektedir. Bu sayede, ufak bütçelerle gayrimenkul yatırımı yapılabilmesi, komisyonculara ihtiyaç duyulmadan alıcıyla satıcının bir araya gelebilmesi ve uluslararası direkt yatırımlar mümkün olmaktadır.

Bu tez çalışması, önde gelen menkul kıymet tokenlerinden biri olan gayrimenkul tokenleri üzerine niceliksel ve niteliksel araştırmaları içermektedir. Blokzinciri teknolojisine dayanan menkul kıymet tokenleri, yeni dönem yatırım ürünleri olarak hızla yaygınlaşırken, gayrimenkul tokenleri uzun zamandır bu tokenlerin en popülerlerinden biri olarak öne çıkmaktadır. Bunun altında yatan sebep, gayrimenkul sektörünün düşük likidite ve uzun ve pahalı işlem süreçleriyle ilişkilendirilmesidir. Literatürdeki çalışmalar, gayrimenkul tokenlerinin yapısal kurgusunu analiz etmiş ve gayrimenkul piyasası için önemli bir likidite artışına yol açacağı sonucuna varmıştır. Gayrimenkul varlıklarının tokenizasyonuyla ortaya çıkacak ürünler, piyasaya yüksek giriş engellerini kaldırarak likiditeyi arttıracağı ve aracıların minimuma indirildiği ikincil bir piyasa oluşacağı için, tokenizasyon platformları ve emlak piyasası uzmanları, tokenizasyonun geleneksel pazardaki birçok sorunu çözeceğine inanmaktadır. Kısa sürede geniş bir pazara güvenli erişim sağlayabilen bu teknoloji, teorik olarak hem borç hem de sermaye artırımı için yeni bir platform anlamına da gelmektedir.

Bu çalışmanın amacı, önde gelen varlık tokenizasyonu platformlarından RealT tarafından tokenize edilmiş gayrimenkul varlıklarının finansal verilerini inceleyerek, bu tokenlerin birer yatırım aracı olarak performansını analiz etmektir. Buna ek olarak, çalışma kapsamında gayrimenkul tokenlerinin finansal ürün olarak yapısı incelenmiş, geleneksel ürünlerle benzerlikleri ve farklılıkları tartışılmıştır.

Bu tez çalışması içerisinde, RealT tarafından tokenize edilmiş ve ikincil piyasada işlem gören 151 adet gayrimenkul tokeninin 1 yıllık bir dönemi kapsayan tarihsel veri seti kullanılmıştır. Tokenize edilen bu gayrimenkullerden 139 tanesi Detroit, 12 tanesi ise Chicago'da bulunmaktadır. Tokenize gayrimenkullere ait veri setinden yola çıkarak 4 farklı endeks oluşturulmuştur. Bu endekslerden ilki eşit ağırlıklı fiyat endeksi, ikincisi piyasa değeri ağırlıklı fiyat endeksi, üçüncüsü eşit ağırlık getiri endeksi, dördüncüsü ise piyasa değeri ağırlıklı getiri endeksidir.

Oluşturulan tokenize gayrimenkul endekslerinin performans ölçümü için; risk temelli getiri analizi yapma fırsatı sunan Sharpe ve Sortino oranları ile birlikte finansal varlık fiyatlama modeli kullanılmıştır. Oluşturulan endeksler, referans endeksler ile kıyaslanmış ve sonuçlar paylaşılmıştır. Kıyaslama yapmak adına, tokenize

gayrimenkullerin bulunduğu Chicago ve Detroit'e dair konut fiyat endeksleri (Chicago HI, Detroit HI), benzer bir yatırım ürünü olan ABD'deki gayrimenkul yatırım ortaklıklarının endeksleri (S&P 500 REIT) ve merkeziyetsiz finans piyasasında işlem gören varlığa dayalı olmayan tokenleri konu alan DeFi Pulse Index (DPI) kullanılmıştır.

İlk analizlere göre, riske göre en yüksek getiriye sahip endeks, tokenize gayrimenkullere dair eşit ağırlık toplam getiri endeksi (EWTTR) olmuştur. Riske göre getirisi en düşük endeks ise varlığa dayalı olmayan merkeziyetsiz finans ürünlerini konu alan DeFi Pulse Index (DPI) olmuştur. Sonuç analizlerine göre ise, tüm referans endeksler oluşturulan tokenize gayrimenkul endeksleri karşısında negatif beta değerine sahip olmuştur.

Özetle bu çalışma kapsamında, piyasada aktif olarak işlem gören gayrimenkul tokenlarının finansal performansı belirli referans endekslerle karşılaştırılarak ampirik bir analiz yapılmıştır. Ampirik sonuç, token endekslerinin, riske göre ayarlanmış getiriler bağlamında kripto piyasası ve geleneksel piyasa endekslerine göre olumlu performans gösterdiğini bulmuştur. Bu olumlu performans, yatırımcıların yeni bir yatırım ürünü olan gayrimenkul tokenlerine olan ilgisi ve tokenize edilecek gayrimenkulleri seçen RealT firmasının bir başarısı ile açıklanabilir. Ancak daha sağlıklı bir karşılaştırma yapmak adına, gayrimenkul tokenlerinin sayısı ve ikincil piyasadaki likiditenin artmasının önemli olduğunun altı çizilmelidir.

1. INTRODUCTION

In July 1944, with the Bretton Woods Agreement signed at the United Nations Monetary and Financial Conference convened in New Hampshire, USA, a new system was developed to be used in international payments to determine exchange rates in a way that would improve global trade (Bordo, 1993). With this agreement, which determined the rules of the international monetary system, the International Monetary Fund (IMF) was established and became operational in 1946. Central authorities have been in a very influential position in financial markets throughout time, when the foundations of today's financial environment were laid. In 2008, after the mortgage crisis that caused a global disaster, a still anonymous person or group published a paper called “Bitcoin: A Peer-to-Peer Electronic Cash System”. Paper proposed a new decentralized approach to the current financial environment based entirely on trust. The blockchain technology underlying this approach entered our lives with this paper. Paper proposed a new currency called crypto money that could be used in many areas, especially in international money transfers, and made us reinterpret the definition of money. Bitcoin was just one of the projects that could be created thanks to blockchain technology. In 2014, the Ethereum blockchain was introduced with the paper named “A Next-Generation Smart Contract and Decentralized Application Platform” published by Vitalik Buterin. Basically, the purpose of Ethereum, which can be interpreted as programmable Bitcoin, was to create decentralized smart contracts that are under the control of the consensus mechanism by utilizing blockchain technology, just like a vending machine example. Over time, with the developing blockchain technologies, a wide area of use has emerged, especially for the management of digital assets.

Cryptocurrencies, smart contracts, decentralized unique protocols and of course tokens, which we define as digital assets, have led us to the development of applications that reveal the concept of decentralized finance. In the paper where Chiu and Koeepl (2019) discussed the possibility of settlement of securities on a blockchain and the possible benefits of this, they evaluated the blockchain as a faster, more

flexible and safer settlement area and stated that a valuable area will be created with the appropriate transaction fees under these conditions. With the flexible, fast, secure and transparent structure it offers, one of the industries where tokenization applications are on the agenda is real estate. The number of tokenized real estate assets platforms is growing and blockchain technology is likely to have a significant impact on the real estate market.

The global real estate market as one of the largest markets in the world, is criticized as illiquid and non-transparent due to its high investment costs, expensive intermediaries and market conditions that keep investments tied for a long time (Chapman et al., 2020). While only a few assets can generate the same level of passive income and capital gain over time as real estate, the issue with real estate is that - it is not accessible to everyone (Bade & Hirth, 2016). There are some obstacles such as cash requirements, credit score and international bank accounts to overcome while entering the real estate market (Saull et al., 2020). Moreover, when the investors buy a new property, they face with many third party units to pay various fees like transfer fees, legal fees, exchange costs etc. to complete the asset purchase. All of these operations run the risk of getting involved in underhanded activities including corruption, tax evasion, and money laundering.

Considering that the liquidity of an asset is directly proportional to the supply of the buyers, the liquidity crisis can be coped with solving these problems that reduce the supply (Amihud et al., 2013). At this point, we can leverage tokens, a digital representation of a real-world assets. One of the most compelling use cases of Blockchain technology as a decentralized ledger is that it helps tokenize real-world assets. Using blockchain technology and the self-executing automated smart contracts with specific instructions written in the code will likely help cut through all middlemen (banks, notaries and standard public affairs), and quicken the process (Konashevych, 2020). So in theory, tokenising real estate assets can increase liquidity by minimizing market barriers and maximizing transparency. Creating a liquid, safe and accessible real estate market for all segments of society through the benefits of blockchain technology, can be described as a revolution.

However, real asset tokenization projects are still in the process of adoption. There are still question marks regarding tokenization, on-chain/off-chain transactions and certain underlying structures. In order to achieve the aforementioned revolutionary benefits,

both the technical and legal framework needs to be established. Moreover, the impact of this developing technology on the current real estate market should be regularly monitored.

1.1 Purpose of Thesis

Digital representations of securities on the blockchain, including real estate assets, are called security tokens. Smart contracts, which are computerized transaction protocols that carry out a contract's provisions, are the basic component and builder of security tokens (Christidis and Devetsikiotis, 2016). Smart contracts determine how the token can be purchased, traded or even gave dividends in accordance with the system, and all these blockchain based transactions are immutable and fully transparent (Bharambe et al., 2020).

This thesis aims to investigate the tokenization process of real estate assets, as well as how they are structured as a financial product. In this thesis, which the configuration of real estate tokens issued with the security token offering model will be examined, it will be revealed whether the financial performances of actively traded tokens meet the expectations of society. Moreover, the thesis will empirically examine how selected real estate tokens perform in comparison to the selected benchmarks; S&P 500 REIT indices, DeFi Pulse Index (DPI) and S&P Case Shiller House Price Indices – Detroit & Chicago. In order to make this comparison, a security token index will be developed beforehand. In summary; within the framework of this thesis, publicly traded real estate tokens available for second market trading at Security Token Market will be examined in terms of efficiency and usability along with their economic performances.

1.2 Research Questions

1) How can real estate assets be structured as security tokens using blockchain technology?

2) How to construct Security Token Indices according to actively traded real estate tokens data collected from security token market?

3) How have Security Token Indices performed against the S&P 500 REIT indices, DeFi Pulse Index (DPI) and the Case-Shiller MI Detroit - Chicago House Price Indices?

2. BACKGROUND

2.1 Blockchain Technology

Blockchain or Distributed Ledger Technology (DLT) is a type of database that is not under central control. As the name suggests, blockchain stores data in interconnected blocks. It encrypts the data with a cryptographic function called the hash function and stores it uniquely using the timestamp. While more than one type of blockchain can be created, what makes this technology valuable is its three carriers, the internet, cryptography and consensus mechanism.

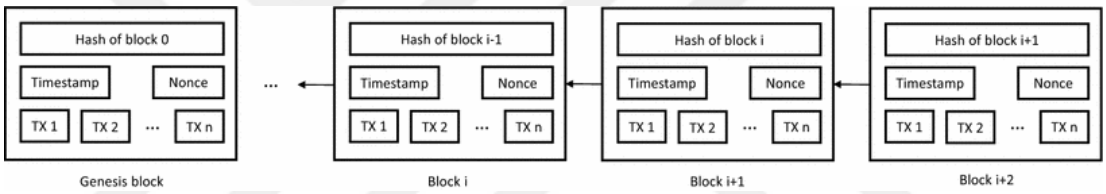

Figure 2.1: Example of a Blockchain (Zheng et. al., 2016)

A schematic example of a blockchain is shared in Figure 1. A blockchain consists of interconnected datasets, where each block contains multiple transactions (TX1-n, see Figure 1) (Zheng et. al., 2016). Each new block attached to the chain expands the chain and represents a complete ledger of transaction history. All blocks in the chain can be verified by the network using cryptographic tools. In addition to transactions, each block contains a timestamp, the hash value, which is the output of the previous block generated by cryptographic functions, and a random number nonce to verify the hash value. This is how the integrity of the entire blockchain is ensured, starting with the genesis block, which is the first block in a blockchain. Since these hash values generated through cryptographic functions are unique, any change that can be made to any block over time will occur instantly, thus preventing all fraudulent or malicious activities. For new blocks to be added to the network, the majority of nodes in the network must agree on the validity of transactions.

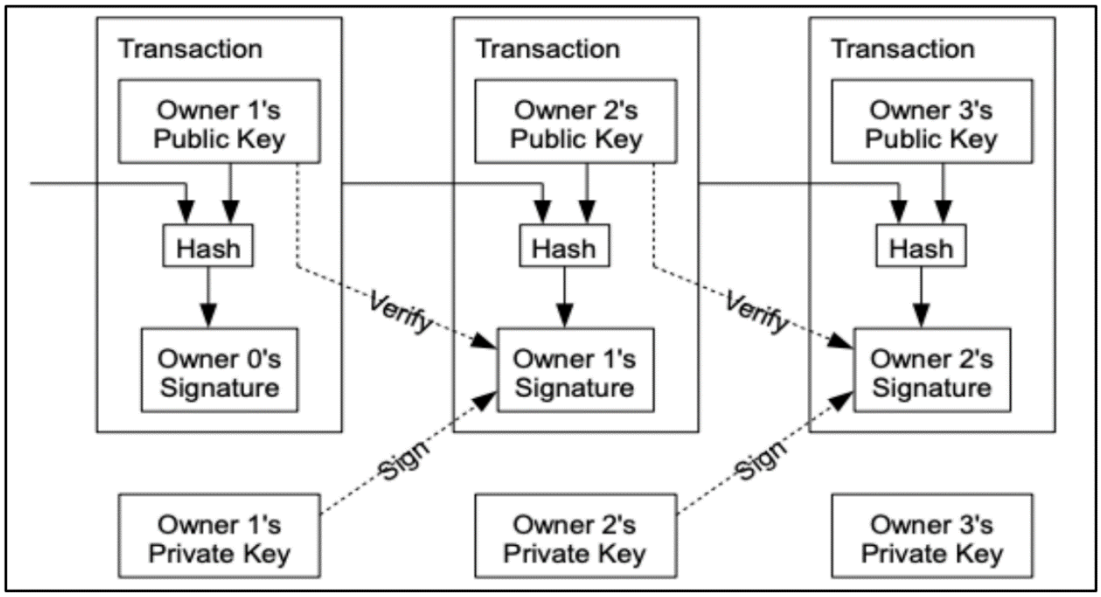

Figure 2.2: Public and Private Keys Concept in Bitcoin Transactions (Nakamoto, 2008)

Swanson (2015) defines the consensus mechanism that governs this consensus process as a set of procedures for maintaining a coherent set of facts. Due to this whole reconciliation process, new transactions are kept for a certain period of time and added to the ledger after reconciliation, instead of being automatically added to the ledger. For example, in the Bitcoin blockchain, this time is 10 minutes. New transactions added to the ledger cannot be changed later. In addition to mechanisms such as Proof of Work and Proof of Stake used for the consensus mechanism, many new mechanisms are on the agenda. In summary, the 3 pillars of blockchain technology are; cryptography, consensus and the internet. Using this peer-to-peer system, people from different parts of the world can safely transfer assets without the need for a central authority (Nofer, 2017).

2.1.1. History of blockchain

Blockchain technology was introduced in November 2008 with the paper “Bitcoin: A Peer-to-Peer Electronic Cash System” published by a person or group named Satoshi Nakamoto. Soon after, in January 2009, the bitcoin software was released on sourceforge.com. The first Bitcoin transfer took place between Satoshi Nakamato and cryptographer Hal Finney. Bitcoin was announced as a digital currency that is not tied to any central bank or central authority, using blockchain technology. The supply of

Bitcoin, which can be transferred from user to user in the Bitcoin network without the need for intermediaries, was designed to be limited to 21 million.

2.1.2. Types of blockchain

Blockchains can be developed in 4 different types: public, private, hybrid and federated.

2.1.2.1. Public blockchains

Blockchains which anyone can join, send transactions and participate in the consensus procedure without any permission are called public blockchains. The prime example of public blockchains is the Bitcoin blockchain. Each peer has a copy of the decentralized ledger kept and can read it at any time. Besides, public blockchains can be joined at any time via any computer with an internet connection. Public blockchains need peers to provide the consensus mechanism, each participating computer can act as a peer. This consensus method can be Proof of Work, which has an example in the Bitcoin chain, Proof of Stake that the Ethereum chain is transitioning to, or one of many developing mechanisms. If the participating peers make the necessary calculations and provide the necessary validations correctly, they contribute to the system and receive their reward. The advantages of public blockchains are easy access to the network, decentralization, transparency, and trust through peers without any intermediaries. The disadvantages include low transaction speed, scalability problem caused by more nodes, and relatively high transaction fees. In addition, the high energy consumption of the Proof of Work (PoW) mechanism can be shown as a disadvantage. Moreover, public blockchains have an important place in the philosophy of decentralization. An example public blockchain structure is shown in Figure 3.

Figure 2.3: Types of Blockchains – Public Blockchain (Iredale, 2021)

2.1.2.2. Private blockchain

Private blockchains are those in which only authorized or approved peers can join the network. These blockchains, often used by banks or private companies, are developed to secure underlying data that is not publicly available. Private blockchains are not decentralized because there is an authority by which participants are selected or approved. Since the number of peers is small compared to public blockchains, consensus can be reached much faster than public blockchains. In private blockchains, the decision makers are only the central nodes, not all nodes. Private blockchains are used in financial product and asset tokenization projects that are being developed by large banks recently. At the same time, it is actively used in developed supply chain management projects. The advantages of private blockchains are that they are fast and scalable due to the low number of nodes. The disadvantages are that they are similar to traditional methods due to their decentralization and are weak compared to public blockchains in terms of reliability and transparency. An example private blockchain structure is shown in Figure 4.

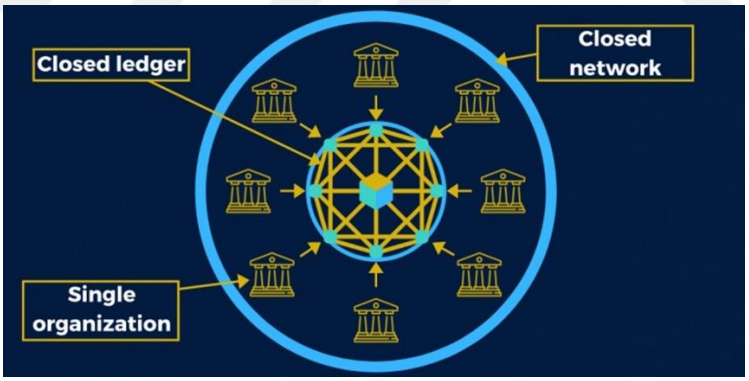

Figure 2.4: Types of Blockchain – Private Blockchain (Iredale, 2021)

2.1.2.3. Hybrid blockchain

Hybrid blockchains can be defined as a combination of public and private blockchains. They are developed to combine the positive aspects of public and private blockchains. The aim is to provide freely controlled access. Hybrid blockchains have the ability to organize some transactions privately and some publicly. That is, it allows organizations to set up a permission-based system rather than a public one, and enables them to control who can access the data held on the blockchain. The advantages of

hybrid blockchains can be listed as being private but still partially public, being more scalable compared to public blockchains, and therefore high transaction speed and low transaction cost. The downside is that they are not as transparent as public blockchains. Hybrid blockchains are an important solution for use in financial markets, with critical data being private and the rest transparent (Alkhateeb et. al., 2022). An example hybrid blockchain structure is shown in Figure 5.

Figure 2.5: Types of Blockchain – Hybrid Blockchain (Iredale, 2021)

2.1.2.4. Consortium (Federated) blockchain

Consortium blockchains, which have a similar structure to private blockchains, are blockchains controlled by more than one organization. They can be described as partially decentralized since there are multiple controllers in the network. Since more than one organization constitutes the control mechanism, when there is any illegal or undesirable activity, it can be exposed by one of the organizations, this is where it gets its partial decentralization. The main motivation for creating consortium blockchains is to help businesses collaborate with each other. While the advantages of consortium blockchains are that they have a more scalable and more efficient structure compared to public blockchains, their disadvantages include that they are not as transparent as public blockchains. An example consortium blockchain structure is shown in Figure 6.

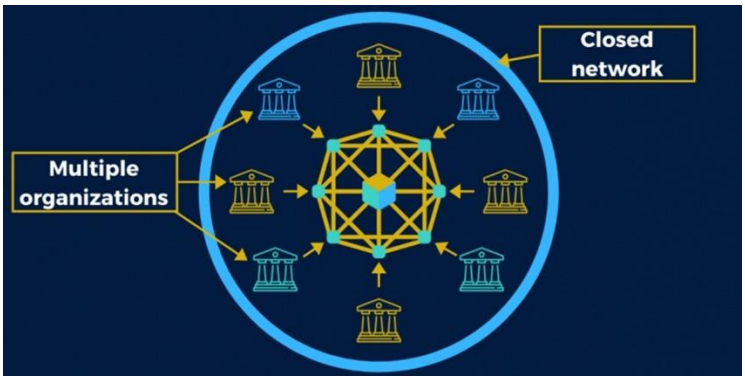

Figure 2.6: Types of Blockchain – Consortium Blockchain (Iredale, 2021)

2.2 Security Tokens

Security tokens are financial instruments that indicate ownership of an asset with the benefits of blockchain technology. A security token also can be defined as a digital reflection of any investment product written on a distributed ledger, which takes place under the control of securities laws (Lambert et al., 2022). From a technical point of view, a security token in this blockchain-based helix is a piece of code that encapsulates the underlying asset as a programmable string of numbers, commands, and parameters. While the parameters or instructions processed on the token during the development process vary according to the expectations on the token, the basic ones can be listed as follows:

- Number of total tokens issued

- The amount of the underlying asset represented by each token

- Type of investment instrument

- Type of investor allowed (Accredited, Institutional etc.)

- Permitted jurisdictions for investors

- Distributions (percentage, amount, tiers)

- Lock-Up periods or trading limits

Each of these parameters can be coded uniquely to the security token via smart contracts and can be self-managed with a limited number of broker fixes. Here, the feature that smart contracts offer us is that the rules based on the parameters given above are automatically executed without the need for any intermediary or central authority. Digital ownership on blockchain fulfills a key need in the current financial

system, with real-time fast and seamless trading, unbreakable trust, global access to capital, and lower operating fees than traditional markets (Chen and Bellavitis, 2020).

Security tokens cover many types of assets, such as individual real estate, private investment funds (PE/VC), income-backed businesses, public stocks, IPOs, art and collectibles investments. Building on the examples given, security tokens provide tangible and partially centralized value through being fundamentally asset-based, while having the exchangeability and transferability of cryptocurrencies such as BTC and ETH.

The development process of a security token includes 5 steps:

(1) Asset Selection

(2) Offering Structuring

(3) Technical Development

(4) Primary Token Issuance

(5) Secondary Token Trading

Security tokens that have reached the final stage can be traded just like any publicly traded stock on the NASDAQ, and can exist in secondary markets as long as they continue to perform.

After the asset selection is made, the offering structuring phase starts. The setup of smart contracts that create security tokens enables the security token structure to take various forms. These forms are; equity, debt, income sharing, profit sharing or mixed models that can be created from them. Just like airdrop events in emerging cryptocurrency networks, loyalty rewards, bonuses and various utility applications can also be created for security tokens.

Equity is ownership of the underlying asset. Equity tokens, which contain a similar contract structure as stock certificates in traditional markets, are recorded in a blockchain, unlike traditional ones. If we give an example for real estate; It is a representation of the shareholding in a real estate. An equity token may also grant its holder the right to vote in voting on the underlying asset, or the right to earn dividends if it exists in the structured structure.

Debt tokens are tokens that represent a debt or cash, similar to short-term loans with an interest rate for a specific principal amount lent to the company. It is equivalent to debt-financed capital. Some debt instruments, such as real estate mortgages and corporate bonds, are represented by debt security tokens. Two major factors influence the behavior of these tokens are risk and dividends. Here, risk represents the default of the debtor or sudden changes in debt amounts, as in traditional financial markets. With the contribution of blockchain technology, token issuers can encode their offerings into the smart contract and configure the process so that a predetermined rate is distributed (Sazandrishvili, 2020).

Security tokens are inherently developed on blockchains that support smart contracts. Currently, the most prominent blockchain at this point is the Ethereum blockchain, which also includes the tokens used in the quantitative research part of this thesis. However, as mentioned in the current literature, many studies are being carried out for the transition to scalable blockchains with appropriate transaction fees.

2.3 Special Purpose Vehicle

A Special Purpose Vehicle (SPV) or Special Purpose Organization (SPE) is a legal entity established by an originator with the transfer of assets to perform a specific purpose or limited activities. The rules governing SPVs are predetermined, so they cannot deviate from the purpose for which they were created and make important decisions. This structure does not have a physical location or employees. SPVs usually have a limited partnership or limited liability company structure. Gorton and Souleles (2007) defined the general characteristics of SPVs as follows:

1) Assets held by the SPV are serviced through the service arrangement.
2) Decisions regarding administrative functions and cash management are taken in advance and the decisions are carried out.
3) They are structured in such a way that they practically do not go bankrupt.
4) They are robotic structures that are the place where decisions are implemented and cannot make new economic decisions.
5) Off-balance sheet financing arrangements can take the form of financial leasing transactions or asset securitization.

The main purpose of establishing Special Purpose Vehicles is to deal with asset acquisition or asset financing. Such subsidiaries are formed to isolate the financial risk

of the parent companies. Accordingly, one of the objectives is to securitize debts that would be repaid by investors if the parent company defaults (Drury and Hayes, 2021).

3. LITERATURE REVIEW

3.1 Blockchain and Smart Contracts

The article titled “Bitcoin: A Peer-to-Peer Electronic Cash System” published under the pseudonym Satoshi Nakamoto in 2008 was instrumental in the emergence of blockchain technology. In his article, Nakamoto (2008) explained the cryptocurrency and the underlying blockchain technology created through this peer-to-peer system based on digital trust without the need for intermediaries. Nakamoto's published article opened a new field of research by being the subject of 41 peer-reviewed journal articles by 2015 (Choi et. al., 2016). Subsequently, 2000 peer-reviewed journal articles were published on bitcoin and blockchain technology, which gained momentum between 2015-2018 (Anascavage & Davis, 2018). Also, as Vitalik Buterin underlined in his paper titled “Next-Generation Smart Contract and Decentralized Application Platform” in 2014, programmable crypto assets that can be created through blockchain technology signaled developments that could be revolutionary not only in finance but also in many fields.

One of the important developments accelerating the rise of blockchain technology is the smart contracts that can be created thanks to this infrastructure. Szabo (1994) first introduced the concept of smart contracts, a machine-driven digital representation of traditional contracts. With today's blockchain technology, the implementation of smart contracts which introduced by Szabo about 30 years ago, has become much easier and more reliable. With the advanced technology, even the lawyers or banks involved in traditional contracts may not be needed for asset and ownership agreements (Fairfield, 2014). According to Fairfield (2014), tangible properties such as real estate or intangible properties such as stocks can be controlled as digital assets.

Main development that made smart contracts gain popularity is Ethereum, a system created by Buterin (2014). Buterin (2014) announced the Ethereum project in his paper titled “A Next-Generation Smart Contract and Decentralized Application Platform”, claiming that trust can be provided in a decentralized way without the need for third-

party applications or intermediaries. Glaser and Bezzenberger (2015) evaluated this technology in 3 broad categories in their article examining the taxonomy of the consensus mechanism behind cryptocurrencies. These were; cryptocurrencies are decentralized autonomous organizations (DAO) and distributed ledger technologies (DLT). As a result of the study, it was shared that a much wider application area such as voting systems, digital ownership and supply chain management will emerge beyond cryptocurrencies through smart contracts developed with blockchain technology (Glaser and Bezzenberger, 2015).

Treleaven et. al. (2017) argue that blockchain technology can lead to significant changes in the financial industry through smart contracts. It has been shared that the trust needed in financial markets can be achieved with decentralized smart contracts, and at the same time, efficiency will increase with the reduction of transaction costs, but problems such as interaction capability and scalability must be overcome before implementation (Treleaven et al., 2017).

On the other side, Zheng et al. (2020), Khan et al. (2021), Ante (2021) investigated the potential application areas of smart contracts in their published studies and evaluated their potential effects. While smart contracts have the potential to lead to significant positive changes in all established markets, they can also have a distorting effect in these markets if not properly regulated and developed (Ante, 2021). With the integration of software language processing and artificial intelligence technology, all these potential negative effects can be controlled and a healthier development environment for smart contracts can be created (Zheng et al., 2020).

3.2 Real Estate Tokenization

The real estate sector has become one of the important application areas of blockchain technology with the need for trust and liquidity, as well as being one of all sectors that have had its share of securitization. Many negative features have been underlined in the literature on real estate investments. As it is frequently mentioned in the literature, real estate investment is one of the international investment instruments that has the most obstacles (Sirmans and Worzala, 2003; Newell and Webb, 1996). According to Newell and Webb (1996), high investment costs in market entry increase the level of risk for real estate. On the other hand, Nijland and Veuger (2019) stated the two main characteristics of real estate assets as heterogeneity and inactivity. As a result of these

two factors, real estate investments have negative features such as lack of liquidity, non-transparent market conditions and inefficient transaction processes.

Baum (2020) stated a similar negative feature of real estate investments in his paper and touched on the problem of accessibility in real estate investments. Although real estate is a reliable investment tool, it cannot appeal to all segments of society due to high entry barriers. This can also be cited as a reason for the tokenization of real estate assets. (Baum, 2020) Thus, the literature predicts that in theory, the risk level in real estate investments will decrease and the user base will grow as barriers decrease and transaction efficiency increases with tokenization. There are also many studies in the literature examining the tokenization of real estate assets with a quantitative approach.

Lambert et al. (2020), examined STOs as a fundraising method and listed their advantages and disadvantages by comparing them with traditional initial public offerings (IPOs) and initial coin offerings (ICOs). According to Lambert et al. (2020), Security tokens are digital versions of financial products, but their main record is still on paper or in a centralized database owned by the government and which makes necessary operations slow and expensive. Native Digital Securities, or NDS, will be the next version of securities, which will be able to be programmed on the blockchain. In other words, NDS is a main record of securities that is recognized by the law. It is made as a smart contract on a distributed ledger, which lets on-chain changes and flexible language for describing securities. This will enable enterprises to be managed on-chain, as well as a highly efficient fundraising process.

Benedetti et al. (2019), in their article titled "Tokenized Securities & Commercial Real Estate", they describe the process of creating a digital representation of the asset by processing it on a blockchain as tokenization. According to the authors, tokenization has the potential to revolutionize the real estate industry. Highlighting the advantages of tokenization such as increased liquidity, lower transaction costs and greater accessibility for investors, the article claims that new investment opportunities can be created through this method.

Sharing the legal and technical aspects, Benedetti et al. (2019) addresses the difference between security tokens and tokenized securities. According to this; While both are blockchain-based representations, tokenized securities exist outside the blockchain and can be contacted with specific oracle networks. However, the legal ground on the

subject is still not settled and legal and technical frameworks are needed for tokenization. (Baum, 2020) During the real estate tokenization stages, the owner creates an SPV, the SPV can hold a determined proportion of the shares in the property. The tokens created will also be a representation of the stakes in the SPV (Benedetti et al. 2019).

Schär (2020), in his study examining how decentralized finance works and what advantages and threats it has compared to traditional markets, focused on some basic problems and discussed the concept of decentralization. As a result of the development of DeFi (Decentralized Finance), emergence of new financial instruments may be possible by the use of smart contracts and public blockchains. The potential for malicious use of smart contracts and DeFi's inability to scale present significant security threats. Many protocols and apps hide the fact that they rely on external sources or need a unique administrative key in their usage of the word "decentralized." Schär (2020) claims that DeFi has the ability to help build a more trustworthy and secure financial system if these dangers can be mitigated.

In Konashevych's (2020) article "The General Concept of Real Estate Tokenization on Blockchain", the author discussed the advantages and disadvantages of real estate tokenization, especially the reduction of access barriers and transaction costs while increase in liquidity. Cryptocurrencies, which the author likens to be “colored coins”, have value only for their utility in the blockchain network in which they are located, and are not indicative of any property rights. Real asset-backed tokens, on the other hand, have all the advantages of immutable decentralized ledger, while also representing a property right. Therefore, the value of an asset-backed token has real economic value in line with property rights, with the legal basis being established.

Kreppmeier et al. (2023), in their study investigating the use of security tokens in the real estate sector and their possible effects on secondary markets, shared the conclusion that more efficient trade can be achieved and liquidity can be increased by this way. According to the authors, in addition to the explanatory power of the location factor in real estate, transaction costs associated with the crypto market and the ability to generate cashflow are key factors influencing the success of an STO. In summary, they argue that the characteristics of the cryptocurrency market are significant factors for the success of real estate STOs and capital flows.

Gan et al. (2021), in their paper titled "Initial Coin Offerings, Speculation, and Asset Tokenization", investigated the potential effects of initial coin offerings (ICOs) on financial markets and compared them with security token offerings (STOs). The research concludes that STOs increase higher amounts of funds and corporate profits, along with lower transaction and brokerage costs. According to Gan et al. (2021), offering models can be made more realistic by allowing tokens to be used for things other than buying physical goods, network effects affecting customers' willingness to pay and demand, investors having different ideas about the quality of a product, customers having different prices for the same product. In addition, in the existing literature on STOs, the factors affecting the success in the financing process have been examined by focusing on the issuer and supply characteristics, and similar results have been reached (Lambert et al., 2022; Fisch et al., 2022).

Momtaz et al. (2022), in their paper titled "Blockchain Investors", they researched investors who invested in blockchain technology. In the paper, which examines issues such as investors' characteristics, investment preferences and risk perceptions, blockchain investors are defined as a group that is open to innovation, loves to take risks and wants to open up to global markets. The authors also examined token activity on the Ethereum blockchain and underlined that when transaction costs increase, trading activity decreases. As a result, uncertainties and high transaction costs in the crypto market can indirectly affect all tokens traded on the blockchain. The differences between making investment decisions and risk levels are mentioned in this thesis.

Steininger (2023), in his paper titled "Real Estate Tokens - Return-Risk Analysis of the First Years", examined the current process for retail investors to invest in tokenized real estate and created monthly real estate token indices that can be used for risk-return measures. The author found a low linear relationship between real estate tokens and reference assets (housing market, cryptocurrency market and traditional finance products) and shared the conclusion that real estate tokens can be an attractive part of multi-asset portfolios.

We can also consider that a path to portfolio diversification has been opened through fractional ownership. Goetzmann and Kumar (2008) conducted a study in which they calculated portfolio risks and returns and also investigated the benefits of portfolio diversification. As a result of this study, it has been determined that investors who act consistently with strong biases in their trading decisions exhibit higher diversification.

In the research, it is underlined that 60,000 US investors have insufficiently diversified portfolios and thus face high risk. At this point, we can mention that tokenization will make a positive contribution to diversify the portfolio with the improvement of accessibility conditions in investments.

4. METHODOLOGY AND THEORETICAL FRAMEWORK

4.1 Liquidity Preference Theory

Liquidity Preference theory, put forward by John Maynard Keynes in 1936, is a theory that explains the dynamics of money supply and money demand. The basis of the theory is that people show an interest in money as it is the most liquid and flexible asset and demand develops accordingly. The theory also explains that the demand for money is linked to the interest rate and the price level in the economy, and that investors want higher compensation from medium and long-term investment products (Wells, 1995). According to Wells (1995), agents normally want to maintain their liquidity and accept less flexible options to attract people. For illiquid products, holders must get compensation according to the degree of liquidity.

By examining the different interest rates paid for different bonds, this theory becomes quite revealing. Investors are offered higher interest rates so that they can hold longer bonds. According to Keynes (1936), who explains this theory with three attributes: transactional motive, precautionary motive and speculative motive; liquidity is the ability to quickly and fairly convert an asset into cash.

4.2 CAPM, Beta and Jensen's Alpha

Performance analysis have great importance in the process of making investment decisions. By means of performance measurements, risk and return analyzes can be created and decision-making mechanisms can be developed. All these processes take us to the evaluation stage. The Capital Assets Pricing Model (CAPM), built on Harry Markowitz's portfolio model, was developed to explain the relationship between risk and return mathematically (Elton et. al. 1997). CAPM, which can also be defined as a neoclassical equilibrium model based on simple assumptions, serves to explain the expected returns of risky assets when the capital market is in equilibrium. The slope of the capital market line, which is defined as the linear relationship between the expected returns of portfolios and the risks they bear, shows how much of an effect a

one-unit increase in risk will have on the portfolio return. The risk-free interest rate (Rf) used in the CAPM model is the average interest rate paid on government bonds and treasury bills, while the expected return of the market (ERm) and β (beta) rate (Covariance/Variance) is the index of the stock (or tokens to be used continuously in this study) stands for the sensitivity ratios (Sharpe, 1964).

4.3 Sharpe Ratio and Sortino Ratio

Sharpe ratio, developed by William F. Sharpe, is a tool that helps investors analyze return on investment at risk. Risk or volatility, which is abundant in this mathematics, can be defined as the measure of price fluctuations on any investment instrument (Sharpe, 1964). The Sharpe ratio, which was originally used to measure the performance of mutual funds and called the reward to variability ratio, is the most popular of the single-parameter metrics used to measure the performance of portfolios. A higher Sharpe ratio represents a more positive portfolio return.

Sortino ratio, which is used to measure the portfolio's risk-adjusted return, is calculated by dividing the portfolio's return by the downward deviation of the asset after deducting the risk-free interest. Sortino ratio, which is an effective method for comparing portfolios with high volatility in relatively short time periods, separates harmful volatility from total volatility rather than the total standard deviation in portfolio return by using the standard deviation of negative portfolio returns of the asset, and differs from Sharpe ratio in this aspect. Just like the Sharpe ratio, a higher Sortino ratio is indicative of better performance. An investment with a higher Sortino ratio between two identical investments means that it can generate more return per unit from bad risk (Sortino et. al., 1994).

4.4 Four Central Moments of Distribution

Four Central Moments of Distribution is a measure group that describes the properties of a distribution. The first and most popular of these measures, mean, describes the mean value of a distribution. The second is variance. The variance is the mean squared of their distance from the mean value in a distribution. It explains the value distribution, it is used in the definition of volatility in finance. The third is skewness. Skewness measures whether, in essence, a distribution is symmetrical. If a distribution

is not symmetrical, then the skewness takes a value other than 0. The fourth, kurtosis, measures the intensity of the extreme values of a distribution. If a distribution has many extremes, then the kurtosis value will be higher than the normal distribution. When Kurtosis and Skewness values are between -1.5 and +1.5, it is considered to be a normal distribution (Tabachnick and Fidell, 2013).

5. DATA

5.1 Research Approach

Within the scope of this thesis, three different research questions will be examined. Qualitative research methods will be used for the 1st research question, and quantitative methods will be used for the 2nd and 3rd research questions.

5.2 Data Selection

In order to work on the 2nd and 3rd research question; The actively traded real estate token data, organized by RealT, is downloaded from the Security Token Market (stomarket.com). These tokenized real estates include 151 residences located in the cities of Chicago and Detroit in the USA. In order to compare the Security Token Index to be created, 5 different benchmarks will be used. Two of them are S&P Case-Shiller MI-Detroit (DetroitHI) and S&P Case-Shiller MI-Chicago (ChicagoHI) as real estate tokens are located in these regions. The source of this data will be the Federal Reserve Bank. Another benchmark chosen is the S&P 500 REIT index. (Federal Reserve Bank, 2022) The risk-free rate data used is three months US treasury bill30 (DGS3MO) (Federal Reserve Bank, 2022). Finally; In order to observe the relationship between the DeFi market and the security token market, the DeFi Pulse Index was taken as a benchmark.

5.3 Index Construction

The tokens collected in dataset were filtered according to their location. (Of 151 tokens, 12 are in Chicago and 139 are in Detroit.) Dividend payable and non-dividend returns will be calculated based on the average market values of each month. It is planned to create 4 separate indices from all these tokens. These created indices are compared with the benchmarks determined respectively:

EWT - Equally Weighted Price Return

EWTTR - Equally Weighted Total Return

MWT – Market Cap Weighted Price Return

MWTTR – Market Cap Weighted Total Return

6. RESULTS

6.1 Structure of Real Estate Tokens

Once real assets are securitized and offered through the primary markets, the security tokens created can begin to be actively traded in the secondary markets. Any provisions on trading transactions, lock-in periods and functions such as jurisdictions can be specified in the original offer. Real estate assets that follow this process can be tokenized and take an accessible position in the secondary markets. This ecosystem, which has developed as a function of primary offers, will continue to grow as its popularity increases and institutional investors join the chain.

After the Initial Coin Offering (ICO) concept, which gained popularity in 2018, security tokens has also began to appear in the markets. But most of the use cases at those times were for organizations such as crypto investment portfolios and crypto VC funds to provide cash flow and fractionate dividends. In December 2019, 9943 Marlowe St., tokenized by the RealT platform and traded on the secondary market, emerged as the first real estate asset to be tokenized on the Ethereum ERC-20 network. Subsequently, the number of real estate assets tokenized in this network has well exceeded 180 and is still increasing. While RealT focuses on the tokenization of residences, there are also 6 commercial properties tokenized by different organizations. These; Aspen Coin, Tinaga Island Resor, FirstShot Centers, Myra Park, SiriHub A and SiriHub B. Residences can be considered a stronger application area in terms of sustainability and efficiency of the tokenization process, with a lower market value than commercial properties.

Real estate tokens can be operated by an organization or individuals, generating income through their tenants and sharing it with shareholders using blockchain technology. The operator of the property is usually the owner of the property or the common denominator of the raised capital. Responsible for property management, supervision and asset management. Through Decentralized Autonomous Organizations (DAOs), another benefit of blockchain technology, all decisions on the

property can be taken with the transparent and unalterable consensus of the shareholders, and the implementation status can be tracked. At the same time, while the structure of the created token is being designed, the operating company takes a position accordingly.

Registration of real estate or fracturing of land ownership is legally and technically very difficult globally, so it is necessary for the legal basis for the owner to form an SPV in the form of a limited liability company (LLC). Shares that arise through SPVs are then called securities and assets are created on the blockchain via a token platform. The real estate tokens used and widely invested in this thesis are traded on the Ethereum blockchain, which is a public chain. Real estate tokens traded on public blockchains meet all of the transparency requirements, unlike private blockchains.

With the creation of the token on the blockchain, inter-individual trading of the ownership of this token and distribution of the resulting dividend income can be achieved through smart contracts. All this process is managed in a decentralized way. Token holders represent a certain share of the relevant real estate asset as well as shares of the SPV holding the dividend right.

6.2 Data Analysis

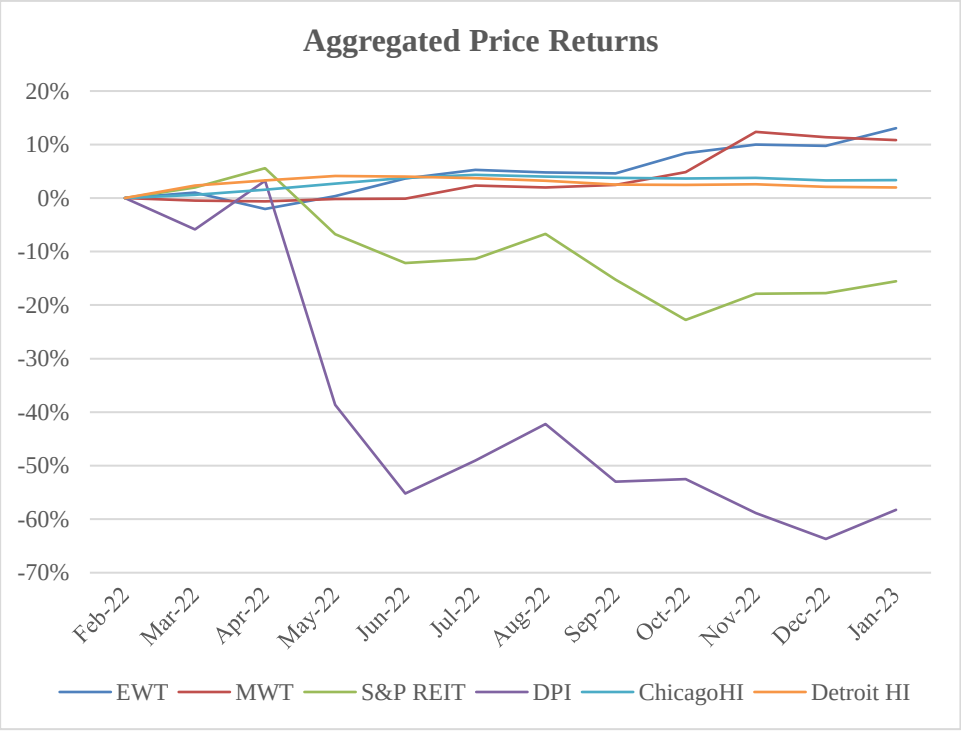

Figure 6.1: Graph of the aggregated price returns for the one-year period

Figure 5 shows the 1-year performance graph of price returns for price-based token indices and reference indices for the range of February 1, 2022 – February 1, 2023. The equally weighted price return (EWT), one of the real estate token indices created, showed the best performance in total one-year price returns with a value of 13.05%. The market cap weighted token price index (MWT) provided a return of 10.84%. Meanwhile, in Chicago, where these real estate tokens are located, the House Index returned 3.33% and in Detroit, the House Index returned 2.00%. The S&P500 REIT index, which includes REITs created for accessibility to real estate investments, presented a negative return of -15.53% at the end of one year. In this 1-year date range, DeFi investments, whose relationship with real estate tokens are frequently examined in the literature, created a negative return of -58.24%.

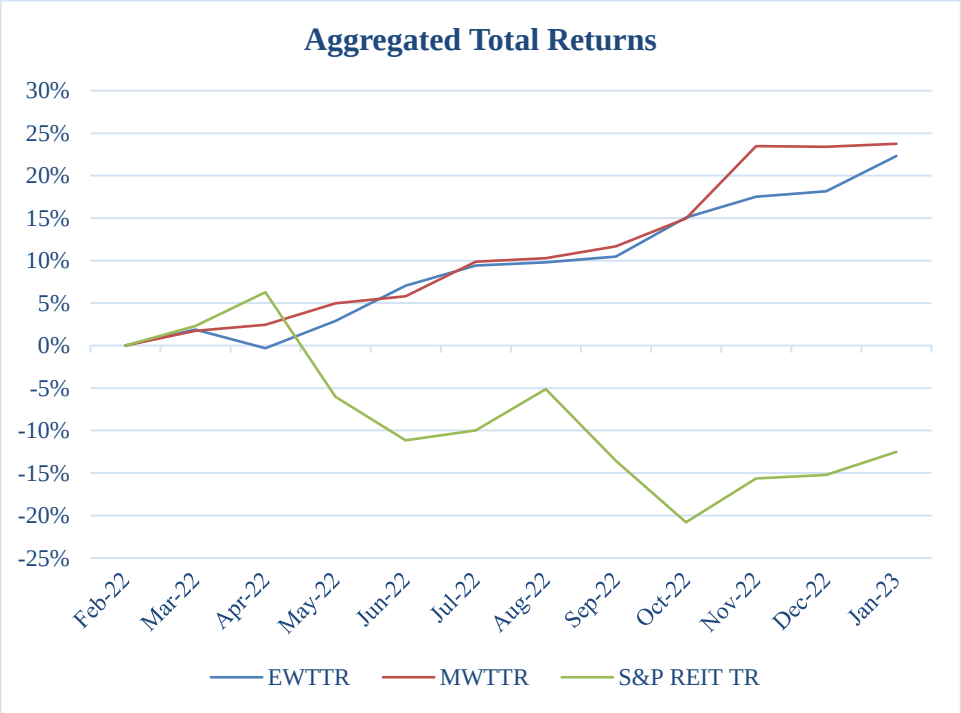

Figure 6.2: Graph of the aggregated total returns for the one-year period

Dividend income from real estate tokens was evaluated as monthly reinvestment and total return indices were created. Among the indices created, the market-weighted total return index (MWTTR) provided a return of 23.71% and the equally-weighted total return index (EWTTR) of 22.31% at the end of the 1-year period. Meanwhile, the S&P REIT Total Return Index offered a negative return of -12.50% at the end of 1 year. While token indices have increased throughout the year, the S&P REIT Total Return

Index experienced a serious decline, especially in the August 2022 – October 2022 range.

Table 6.1: Descriptive Statistics of Token Indexes

	Token Indices			
	EWT	**MWT**	**EWTTR**	**MWTTR**
Mean	0.053	0.041	0.107	0.091
Standard Error	0.014	0.015	0.023	0.024
Median	0.048	0.024	0.100	0.068
Standard Deviation	0.046	0.051	0.076	0.079
Kurtosis	-0.705	-1.039	-0.991	-1.278
Skewness	0.076	0.849	0.132	0.603
Range	0.151	0.130	0.236	0.201
Minimum	-0.020	-0.006	-0.004	0.004
Maximum	0.131	0.124	0.232	0.205
Count	11	11	11	11

The table contains descriptive statistics analyzed for token indices. The standard deviations of the token indices expect MWT, gave a lo”wer result than their mean. In particular, the market weighted total return index (MWTTR) offers a remarkable statistic in this direction. All generated token indices have negative kurtosis. Negative kurtosis is indicative of a relatively flat distribution. Skewness also revealed positive results for each index.

Table 6.2: Descriptive Statistics of Reference Indexes

	Reference Indices				
	S&P500 REIT	**S&P 500 REIT TR**	**DPI**	**Chicago HI**	**Detroit HI**
Mean	-0.107	-0.092	-0.431	0.031	0.029
Standard Error	0.026	0.024	0.066	0.003	0.002
Median	-0.121	-0.111	-0.525	0.036	0.025
Std. Deviation	0.086	0.080	0.219	0.011	0.007
Kurtosis	-0.093	0.115	1.238	1.682	-1.430
Skewness	0.746	0.753	1.513	-1.511	0.400
Range	0.283	0.270	0.669	0.037	0.021
Minimum	-0.227	-0.208	-0.637	0.005	0.020
Maximum	0.055	0.062	0.032	0.043	0.041
Count	11	11	11	11	11

While the standard deviation of Case&Shiller Chicago House Index and Case&Shiller Detroit House Index, which are taken as reference indices, is lower than the mean; The DeFi Pulse Index showed a significantly higher value than the mean standard deviation of the S&P 500 REIT Price Return Index and the S&P 500 REIT Total Return Index. The Kurtosis value gave a negative result for the S&P 500 REIT Price Return Index and Detroit Housing Index.

Table 6.3: Sharpe ratio, Sortino ratio, volatility and arithmetic mean excess returns for the constructed real estate token indexes and reference indices

	Arithmetic Mean E.R.	Volatility	Sharpe Ratio	Sortino Ratio
MWT	0.014	0.037	0.382	N/A
MWTTR	0.065	0.064	1.009	N/A
EWT	0.027	0.032	0.853	1.740
EWTTR	0.080	0.061	1.324	N/A
DeFi Pulse Index	-0.458	0.232	-1.970	-2.578
S&P 500 REIT	-0.134	0.100	-1.341	-1.794
S&P 500 REIT TR	-0.119	0.093	-1.272	-2.031
Chicago HI	0.005	0.012	0.411	1.012
Detroit HI	0.003	0.021	0.134	0.367

In Table X, the arithmetic mean excess return, volatility, sharpe ratio and sortino ratio values of all indices used in the study are shared. Accordingly, the equally weighted total return index (EWTTR) for real estate tokens has the highest sharpe ratio of 1.32. In general, real estate token indices have higher sharpe ratio than reference indices. DeFi Pulse index showed the worst performance among the reference indexes. Sortino Ratio, on the other hand, could not be calculated for real estate token indices that do not have a negative return period.

Table 6.4: Beta and Jensen's Alpha for the constructed real estate token indices benchmarked against the selected reference indices

Beta - Jensen's Alpha										
	S&P 500 REIT		**S&P 500 REIT TR**		**DPI**		**Chicago HI**		**Detroit HI**	
	Beta	Alpha	Beta	Alpha	Beta	Alpha	Beta	Alpha	Beta	Alpha
EWT	-0.257	-0.008	-0.268	-0.005	-0.107	-0.022	-1.642	0.035	-1.283	0.031
EWTTR	-0.522	0.010	-0.544	0.016	-0.216	-0.018	-3.371	0.097	-2.649	0.088
MWT	-0.229	-0.017	-0.234	-0.014	-0.092	-0.028	-2.391	0.026	-1.442	0.018
MWTTR	-0.482	0.0001	-0.497	0.006	-0.195	-0.025	-4.107	0.086	-2.766	0.073

7. DISCUSSION

7.1 Structural Review of Real Estate Tokens

The first research question in this thesis is included to explain how real estate tokens are structured as financial products. This question has been answered with an explanatory approach by examining the publications in the academic literature and the structure of the real estate tokens that have already been created. Real estate tokens are based on real assets, which are real estate assets. Depending on the land use; Real estate assets that can be residential, commercial or industrial can become tokens to be defined as a digital asset registered on the blockchain. Although currently traded residential real estate tokens are used in the quantitative research conducted within the scope of this study, there are also commercial real estate tokens that are currently traded.

It is worth noting that real estate tokenization technology will gain momentum with the development of the legal infrastructure. At this point, the policies to be developed by the USA and the European Union in the upcoming period will play an important role in the introduction of the relevant technology into our lives. Although there are still major obstacles to the tokenization of land or title deed (Konashevych, 2020), the tokenization of real estate assets has progressed and gives important signals for portfolio diversification.

The real estate market (Gupta et al. 2020), which is currently dominated by large-scale investors, can also create an opportunity for small-scale investors with tokenization technology. Small-scale investors who cannot access the real estate market due to high barriers to entry can take positions to access real estate assets through fractional ownership (Benedetti et al. 2019). The democratization of this investment vehicle can also increase liquidity in the real estate market and could be the start of a revolution for real estate assets that have historically been characterized as an illiquid asset (Gupta et al. 2020). In addition, a faster and more efficient way for real estate owners to raise capital can be created through the created tokens (Baum, 2020).

Developments regarding the legal and technical framework for the tokenization of real estate assets continue every other day. Currently, distributed ledger technology (DLT) is used to create tokens, a financial instrument created to invest in real estate. An intermediary institution is required to establish the ownership or the claim of ownership over the related asset. These intermediary institutions are represented as a limited liability company under the name of special purpose vehicle (SPV). The SPV is capable of representing all or part of the property. Cash flow in the underlying asset can be passed on to investors in the form of dividends, and tokens that represent property as well as dividend rights are called equity tokens and can also be defined as stocks in traditional markets registered on the blockchain. By the same methods, debt tokens similar to bonds can be created, in which token holders will be paid a predetermined interest rate. Benedetti meat. get. (2019), these security tokens, which have the characteristics of a security, should be regulated in accordance with securities laws. With the SEC laws being followed, investors considering investing in these tokens can meet with a secure and legally binding infrastructure.

The most commonly used blockchain by tokenization platforms is Ethereum with ERC-777 standards. (Gupta et al. 2019) The Ethereum blockchain, which has developed important solutions to the scalability problem, as well as accepting tokens on the network, stands out as the most popular blockchain in this field. The real estates tokenized by the RealT platform used in this study are also included in the Ethereum blockchain.

While cryptocurrencies have value in line with their benefits in the blockchain network they are in, security tokens derive their value from their underlying assets. The structural difference between them has been the subject of discussion in the literature for a long time (Kreppmeier, 2023). Within the scope of this thesis, the structural differences are expressed in an explanatory way, and the performance difference between these two decentralized investment products is discussed in the quantitative part.

7.2 Empirical Characteristics

The second question addressed in this thesis is how to construct an index for real estate tokens that are actively traded in secondary markets; The third question was how the constructed real estate token indices performed compared to reference indices. As

reference indexes in the study; S&P 500 REIT index for REITs that are a tool to invest in real estate with a low budget and partially similar to real estate tokens, Case-Shiller House Price Indices for Chicago and Detroit where the tokens are the source of the indices, and DeFi, which is the representation of decentralized finance tokens representing the crypto market Pulse Index is selected. The index for Real Estate Tokens was created from 151 Real Estate Tokens tokenized by the RealT platform and actively traded in secondary markets. Since real estate tokens share dividends, namely rental income, with their investors, price return and total return indices were created separately and evaluated separately with reference indices.

The date range included in the study covers the range of 1 February 2022 – 31 January 2023. While the number of actively traded tokens was 146 in February 2022, this number reached 151 in January 2023. Among the token indices created, EWTTR (Equally Weighted Total Return Index) offered the highest return with 23.20%. Another total return index MWTTR (Market Weighted Total Return Index) provided a return of 20.49%. MWTTR, which has a larger skewness value than EWTTR, indicates that historical returns are more spread out with this result. A similar comparison can be made for the price return indices MWT and EWT. MWT, which has a rather large skewness value compared to EWT, presents a broadly spread-out data. The index with the lowest volatility among token indices came to the fore as EWT. The volatility of the volume-weighted indices appeared higher than the equally-weighted indices.

Indices, which have experienced positive growth over the 1-year historical range, signaled a positive return will be offered with dividends reinvestment. At the end of 1 year, MWTTR had a positive difference of 9.65% compared to MWT and EWTTR had a positive difference of 10.15 % compared to EWT. The averages of all indices, except MWT, were higher than their standard deviations. This can be interpreted as a positive signal for real estate tokens to separate from the high-risk investment products group in the financial framework.

When we look at the Sharpe ratios, which can be described as a measure of expected return per unit of risk, EWTTR showed the best performance with a Sharpe ratio of 1.34. In general, the Sharpe ratio of token indices gave a high result compared to reference indices. The reason why we observe a very high Sharpe ratio compared to the crypto market is that these investment products are based on real assets. Compared

to REITs, tokens targeting a private real estate selected by the company offered a higher Sharpe ratio with higher returns and less volatility. Although the token indices have higher volatility compared to the Detroit and Chicago housing markets, they still offer a higher Sharpe ratio thanks to the returns. Again, at this point, it is significant to underline the success of the issuer company.

The token indices gave a positive alpha value for the Chicago and Detroit home price indices, while the DeFi Pulse Index gave a negative value for the index. Price Return Token Indices also gave REITs negative values, while Total Return Token Indices gave positive alpha values. The beta value, which is an explanatory value for systematic risk or volatility within the scope of this study, took a negative value in all reference indices against token indices. At this point, it can be said that a positive correlation could not be determined.

8. CONCLUSION

In this thesis, the tokenization of real estate assets was investigated both empirically and theoretically and the findings were shared. As a result of the developments following the emergence of blockchain technology, the idea of tokenization of real estate assets gained popularity in a short time and was adopted by those interested in this technology. In order to examine the financial product structure and performance of these tokens in detail, 3 research questions were determined and their answers were discussed.

Although real estate tokens are the product of a new technology, its structural setup as a financial product is similar to some products in traditional markets. Equity tokens are similar to stocks in traditional markets, while debt tokens used for raising capital are similar to bonds. Unlike traditional products, these tokens created through Distributed Ledger Technology (DLT) provide transaction efficiency and access to wider markets in a short time. At the same time, these tokens can be defined as a digital representation on the blockchain of a limited liability company holding the position of ownership.

In the second part of the research, the data of the real estate tokens that are actively traded in the secondary markets were collected and indices were created to evaluate their performance. S&P 500 REIT, Case-Shiller Chicago Detroit House Price Indices and DeFi Pulse Index were chosen as reference indices for comparison. Since real estate tokens are a new financial product, the volume in the traded market was very low compared to traditional markets with a limited trading history. Preliminary results revealed that the total annual return of all real estate token indices offered a better return than reference indices. The increase in the awareness and reliability of blockchain and tokenization technology has increased the number of investors and therefore the total volume in the market, and this result has emerged. On the other hand, the positive results in the returns of the real estates carefully selected and tokenized by the issuer company revealed the success of the company.

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APPENDICES

APPENDIX A: Real Estate Tokens Used in This Study

APPENDIX B: Mathematical and Financial Formulas

APPENDIX A – Real Estate Tokens Used In The Study

Number of Tokens per Index	Token	Dividend / Rent per Token	#
1000	8531 Intervale StDetroit MI 482	6.98	1
19000	19041 Lenore Ave	5.55	2
24000	19000 Fenton St.	5.51	3
14000	14918 Joy Rd	5.56	4
1000	17616 Beland StDetroit MI 48234	6.27	5
8500	12747 Nashville StDetroit	6.06	6
1000	14263 Ohio StDetroit MI 48238	5.3	7
1400	18949 Fenmore StDetroit MI 4823	6.21	8
1000	20418 Andover StDetroit MI 4820	5.46	9
1300	14432 Wilshire DrDetroit MI482	6.28	10
1000	19154 Sherwood StDetroit MI482	5.46	11
1700	882-884 Pingree StDetroit MI 48	6.07	12
1200	15208 Bringard DrDetroit MI 482	6.35	13
1200	116 Monterey StHighland Park MI	5.8	14
1000	14215 Hampshire Token	5.45	15
1000	15841 Coram Token	6	16
1000	11758 Christy Token	6.54	17
1000	14839 Wisconsin Token	6.27	18
1000	14884 Ward Token	6.54	19
1000	15379 Patton Token	5.46	20
1000	12410 Hamburg Token	6	21
1000	15864 Eastburn Token	5.46	22
1600	7109 7111 Pilgrim St Detroit MI	6.02	23
1600	7430 Nett St Token	6.09	24
1700	5772 5774 Chalmers St Detroit M	6.1	25
1800	5278 5280 Drexel St Detroit MI	6.23	26
16000	1521 1523 Drake Token	5.14	27
1100	19191 Bradford Token	7.42	28
1100	10003 Pinehurst Token	6	29
10000	2318-2324 W Marquette Token	5.35	30
1800	893 895 W Philadelphia Token	5.94	31
1100	10021 Grayton Token	6.18	32
1200	15203 Park Grove Token	5.69	33
8200	738 742 E 87th Token	5.23	34
1000	13370 Wilshire Token	6.15	35
6000	14066 Santa Rosa Token	5.9	36

6000	1815 S Avers Ave Token	5.67	37
1300	11957 Olga St Token	5.52	38
2600	12405 Santa Rosa Token	5.61	39
18000	4852 4854 W Cortez Token	5.3	40
1100	12409 Whitehill St Token	5.65	41
1100	13606 Winthrop St Token	5.26	42
1100	19996 Joann Ave Token	5.31	43
15000	11078 Longview St Detroit MI To	5.8	44
8000	1542 Ridgeway Ave Chicago Token	5.38	45
11000	402 Kostner Ave Token	5.36	46
14000	10700 Whittier Ave Token	5.81	47
1200	17500 Evergreen Rd Token	6.05	48
1700	15753 Hartwell St Token	5.86	49
1200	11653 Nottingham Rd Token	6.09	50
1200	19200 Strasburg St Token	5.69	51
1200	18983 Alcoy Ave Token	5.62	52
1200	14494 Chelsea Ave Detroit Token	5.49	53
1200	13045 Wade St Token	5.88	54
1200	10639 Stratman St Token	5.89	55
1200	9920 Bishop St Token	5.95	56
1200	9481 Wayburn St Token	5.95	57
1300	11300 Roxbury St Token	6.36	58
5500	5601 S.Wood St Chicago Token	5.45	59
1200	14229 Wilshire Dr Detroit Token	5.95	60
1200	18776 Sunderland Rd Detroit Tok	5.63	61
1200	17809 Charest St Detroit Token	5.9	62
1200	14882 Troester St Detroit Token	5.79	63
1200	14825 Wilfried St Detroit Token	5.63	64
1200	11078 Wayburn St Detroit Token	5.49	65
1200	15860 Hartwell St Detroit Token	5.78	66
1200	11201 College St Detroit Token	6.07	67
1200	19333 Moenart St Detroit Token	5.71	68
1200	8181 Bliss St Detroit Token	6.75	69
1200	15350 Greydale St Detroit Token	5.67	70
1100	15373 Parkside St Detroit Token	5.83	71
1300	14231 Strathmoor St Detroit Token	6.28	72
11000	1115 South Troy St Chicago Toke	5.45	73
1100	19218 Houghton St Detroit Token	6.49	74
1200	9465 Beaconsfield St Token	5.91	75
1200	19136 Tracey St Token	5.62	76
1200	19020 Rosemont Ave Token	5.9	77
1300	18273 Montevista St Token	5.74	78

1300	15095 Hartwell St Token	5.66	79
1300	18466 Fielding St Detroit Token	5.78	80
1300	15770 Prest St Detroit Token	6.15	81
8000	1244 S.Avers St Chicago Token	3.91	82
1300	19596 Goulburn S Detroit Token	5.24	83
1200	18481 Westphalia St Detroit Tok	5.57	84
1200	15039 Ward Ave Detroit Token	5.49	85
1200	19311 Keystone St Detroit Token	5.54	86
1200	4680 Buckingham Ave Detroit Tok	5.33	87
1800	4061 Grand St Token	5.86	88
1200	19163 Mitchell St Detroit Token	5.74	89
1200	19201 Westphalia St Detroit Tok	5.46	90
1200	9717 Everts St Detroit Token	5.24	91
1200	15796 Hartwell St Detroit Token	5.69	92
1200	17813 Bradford St Detroit Token	5.56	93
1200	4380 Beaconsfield St Detroit To	5.71	94
1200	13895 Saratoga St Detroit Token	6.08	95
1200	14078 Carlisle St Detroit Token	5.62	96
1200	14319 Rosemary St Detroit Token	5.28	97
1300	15777 Ardmore St Token	4.89	98
1300	13116 Kilbourne Ave Token	5.53	99
1800	13114 Glenfield Ave Detroit Tok	6.28	100
1300	15778 Manor St Detroit Token	7.17	101
1300	10604 Somerset Ave Detroit Toke	6.2	102
1300	9133 Devonshire Rd Token	6.45	103
1300	6923 Greenview Ave Detroit Token	5.72	104
1300	13991 Warwick ST Detroit Token	4.59	105
1300	18433 Faust Ave Detroit Token	5.41	106
1300	10974 Worden St Token	6.18	107
1300	12334 Lansdowne Street Detroit	6.32	108
1300	3432 Harding Street Detroit Tok	5.83	109
1300	9169 Boleyn St Detroit Token	6.48	110
1300	10616 McKinney St Detroit Token	5.75	111
1400	9309 Courville St Detroit Token	6.09	112
1300	10612 Somerset Ave Detroit Toke	5.46	113
1400	9166 Devonshire RD Token	6.8	114
1300	9165 Kensington Ave Token	6.82	115
1300	15048 Freeland ST Token	5.72	116
1200	15634 Liberal St Token	6.47	117
1100	18900 Mansfield St Token	5.78	118
1400	18276 Appoline St Token	6.35	119

1400	25097 Andover Dr Token	5.96	120
4000	8342 Schaefer Hwy Token	6.49	121
4000	10024 28 Appoline St Token	16.45	122
1000	9943 Marlowe St Token	8.22	123
750	5942 Audubon Rd Token	9.64	124
1000	20200 Lesure St Token	7.21	125
3800	16200 Fullerton Ave Token	21.82	126
1000	9336 Patton St Token	6.52	127
11800	16767 Greenfield RdDetroit MI 4	5.58	128
13800	3747 Scovel PlDetroit MI 48208	6.42	129
2100	19268 Eureka StDetroit MI 48234	5.48	130
1100	3323 Waverly StDetroit MI 48238	5.5	131
17000	13245 Monica StDetroit MI 48238	5.65	132
12500	7337 S Yale AveChicago IL 60621	4.8	133
12000	11750 Morang AveDetroit MI 4822	5.69	134
2200	9135 Yorkshire RdDetroit MI 482	5.53	135
1100	4000 Taylor StDetroit MI 48204	5.71	136
7000	2626-2638 Wreford StDetroit MI	5.86	137
9500	8017-8019 S Paulina StChicago I	4.38	138
1300	12730 Wade StDetroit MI 48213	5.4	139
1900	5517-5519 Elmhurst StDetroit MI	5.94	140
19000	20160 Conant StDetroit MI 48234	6.04	141
1700	2661-2663 Cortland StDetroit MI	5.79	142
3000	5846 Crane StDetroit MI 48223	5.82	143
1000	18668 St Louis StDetroit MI 482	6	144
1500	19144 Riopelle StHighland Park	5.96	145
6000	9171 Whittier AveDetroit MI 482	5.79	146
1000	20039 Bloom StDetroit MI 48234	5.58	147
1100	19962 Waltham StDetroit MI 4820	5.95	148
6500	13041 Hayes StDetroit MI 48205	6.06	149
6000	8366 Schaefer HwyDetroit MI 482	5.98	150
3500	2950-2952 Monterey StDetroit MI	5.85	151

APPENDIX B – Mathematical and Financial Formulas

Equation 1 - Return

$$R_t = \frac{(P_t - P_{t-1}) + D_t}{P_{t-1}}$$

R_t = *Return*
P_t = *Spot price at time t*
P_{t-1} = *Spot price at time t-1*
D_t = *Dividends* t = *Time*

Equation 2 - Portfolio Return

$$R_{p,t} = \sum_{i=1}^{N} R_{i,t} W_i$$

$R_{p,t}$ = *Portfolio return*
$R_{i,t}$ = *Return of individual asset*
W_i = *Weight of individual asset*
N = *Number of assets*

Equation 3 - Arithmetic Return

$$\bar{R} = \frac{1}{T} \sum_{t=1}^{T} R_t$$

$\bar{R}$ = *Arithmetic return*
R_t = *Return*
T = *Number of periods*

Equation 4 - Volatility

$$= \sigma \sqrt{\frac{1}{T-1} \sum_{t=1}^{T} (R_t - \bar{R})^2}$$

σ = *Volatility*
$\overline{R}$ = *Arithmetic return*
R_t = *Return*
T = *Number of periods*

Equation 5 - Skewness

$$S = \frac{\Sigma_{t=1}^{T} (R_t - \overline{R})^3}{(T-1)\sigma^3}$$

S = *Skewness*
σ = *Volatility*
$\overline{R}$ = *Arithmetic return*
R_t = *Return*
T = *Number of periods*

Equation 6 - Kurtosis

$$K = \frac{\Sigma_{t=1}^{T} (R_t - \overline{R})^4}{(T-1)\sigma^4}$$

K = *Kurtosis*
σ = *Volatility*
$\overline{R}$ = *Arithmetic return*
R_t = *Return*
T = *Number of periods*

Equation 7 - Portfolio Excess Return

$$R_{p,e,t} = R_{p,t} - R_{f,t}$$

$R_{p,e,t}$= *Portfolio excess return*

$R_{p,t}$= *Portfolio return*

$R_{f,t}$= *Risk-free rate*

Equation 8 - Sharpe Ratio

$$S = \frac{\overline{R_{p,e}}}{\sigma_{p,e}}$$

S = Sharpe ratio

$\overline{R_{p,e}}$ = *Arithmetic portfolio excess return*

$\sigma_{p,e}$ = *Volatility of portfolio excess return*

Equation 9 - Beta

$$\beta = \frac{\frac{1}{T-1}\Sigma_{t=1}^{T}\left(R_{p,e,t}-\overline{R_{p,e}}\right)\left(R_{m,e,t}-\overline{R_{m,e}}\right)}{{\sigma_{m,e}}^2}$$

β = *Beta*

$R_{p,e,t}$= *Portfolio excess return*

$\overline{R_{p,e}}$ = *Arithmetic portfolio excess return*

$\overline{R_{m,e,t}}$= *Market excess return*

$\overline{\boldsymbol{R_{m,e}}}$ = *Arithmetic market excess return*

$\sigma_{m,e}$ = *Volatility of market excess return*

T = Number of periods

Equation 10 - CAPM

$$E(\overline{R_p}) = \overline{R_f} + \beta\overline{R_{m,e}}$$

$E(\overline{R_p})$= CAPM predicted arithmetic portfolio return

β = Beta

$\overline{R_f}$ = Arithmetic risk-free rate

$\overline{R_{m,e}}$ = Arithmetic market excess return

Equation 11 - Alpha

$$\alpha = \overline{R_p} = \left(\overline{R_f} - \beta\overline{R_{m,e}}\right)$$

α = Alpha

$\overline{R_p}$ = Arithmetic portfolio return

$\overline{R_f}$ = Arithmetic risk-free rate

β = Beta

$\overline{R_{m,e}}$ = Arithmetic market excess return

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PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS:

- **Bayhoca, B.,** Arslanli, K.Y., (2023). "Structural Review and Performance Evaluation of Real Estate Tokens as a New Era Financial Product," ERES eres2023_290, European Real Estate Society (ERES).