The Role of Smart Contracts in Sustainable Real Estate Transactions and Green Building Initiatives

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Abstract. The purpose of this research is to assess the effect of smart contracts on sustainability outcomes in real estate transactions, with emphasis on the green building concepts. The research question of interest is therefore: how does the application of smart contracts affect sustainability metrics and their relationship with green building certifications? A regression analysis was used to test the hypothesis that link between smart contracts and sustainability performance. The study data was collected from the green building certified real estate projects and smart contracts. The research focused on the impacts of these technologies on transaction clarity, speed and compliance to the environmental standards. The study results suggest that smart contracts are effective in promoting sustainability because they decrease the costs of a transaction and improve organization's adherence to sustainability regulations. The relationship between smart contracts and green building certifications was also significant suggesting that their integration delivers higher levels of sustainability performance than when used separately. This study adds knowledge to the field on how smart contracts may help improve sustainability in real estate transactions especially if combined with green building certification. The findings show how smart contracts may provide a way of enhancing the effectiveness of sustainability management. This paper thus points to the need for policy makers and other industry players encourage use of smart contracts to deliver on sustainable development goals. Future research should elaborate on the ways that are related to smart contracts and sustainability, and other sectors which can benefit from the use of smart contracts.

Keywords: digital transformation, blockchain integration, sustainability metrics, environmental standards, transaction efficiency, eco-friendly business models.

INTRODUCTION

Research problem

Sustainability practices have received much consideration in the different industries, and the real estate sector has emerged as one of the most important sectors owing to the environmental footprint it creates (Kuo, Kim, Ohno-Machado, 2017). Real estate deals with many procedures and huge amounts of money and plays a vital role in the development of sustainable building, particularly green building. Nonetheless, there is still a lack of empirical evidence on the effects of smart contracts and green building certifications on real estate operations' sustainability. This is the research gap that is central to this study because there is a paucity of literature that explains how these digital tools can co-create sustainability.

Research focus

The study is more specifically targeted at understanding how the application of smart contracts along with green building certifications may enhance sustainability performance in the

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real estate sector. As smart contracts are based on the blockchain technology, they enable transactions to be automated and more efficient, whilst increasing the visibility of the process, and, more importantly, contributing to environmental goals. While several industries have embraced the contracts and their possible synergies, the real estate industry has not been very expansive in its application of these contracts to green certifications. This study aims to address the above gap by an attempt to assess how the integration of these two components can enhance sustainability in real estate.

Relevance of the research

It is important to analyze the problem now because the issue of sustainable operations is becoming more important in the light of climate change and environmental issues. Real estate sector is one of the largest drivers of business and environmental footprints and the use of smart contracts can enhance efficiency and extend the number of green building practices. This study can benefit the society by providing significant improvements in the decrease of the carbon intensity of the real estate sector and the improvement of the performance of sustainable business activities. Conceptually, it is the first work that enriches the research gap related to digital innovations in sustainability and specifically in real estate. In this way, the research will help to fill these gaps and offer new knowledge on the use of smart contracts and green certification making a contribution to technological innovations and sustainable developments.

Research aim and research questions

The main focus is on understanding how modern innovations in combination can enhance the sustainability performance indicators such as transaction throughput and compliance with the environmental benchmarks.

To achieve this, the research addresses the following questions:

1. What is the impact of smart contracts on the sustainability of real estate deals especially the green building projects?

2. This question aims at establishing the direct relationship between smart contracts and sustainability measures for instance, the transaction velocity, the level of transparency, and the rate of green certification.

3. What is the result of integrating smart contracts and green building certifications in relation to sustainability?

4. This is with an aim of evaluating the extent to which integration of green building certifications enhances the efficiency of smart contracts in advancing sustainable property management.

Recommendations for policymakers and industry stakeholders on how to best leverage smart contracts and green certifications for improved sustainability in real estate are offered through the following questions. Answering these questions, the work contributes to understanding how digital innovations can contribute to the enhancement of sustainable development in real estate transactions. The implications of the study are relevant for policy makers, industry stakeholders and scholars since the study reveals the concrete advantages of utilizing smart contracts in the attainment of sustainable development objectives.

LITERATURE REVIEW

Based on the literature, blockchain and smart contracts are discussed in many contexts and show many potential benefits and issues regarding sustainability and efficiency in different fields, for instance healthcare, insurance, and supply chains. Kuo, Kim, and Ohno-Machado (2017) look at the Their work shows how blockchain can be used in support of sustainable health care by enhancing data management and enhancing the level of transparency.

In their recent work, Zheng et al. (2018) give an overview of challenges and opportunities related to blockchain that includes the problems of scaling, security, and integration. This survey can be considered as an essential background information to explore the general trends of blockchain technology and its possibilities to eliminate the limitations in the development of sustainable and efficient systems in various sectors. In their study, Gatteschi et al. (2018) examine the current state of the blockchain and smart contracts in the insurance industry in order to ask if the technology is ready for practical applications in the insurance industry. This is important since it helps to determine the preparedness of blockchain in insurance business with regard to the improvement of

sustainability and efficiency through automated and transparent contract management.

Casado-Vara et al. (2018) describe a real-life application of blockchain for the alimentary supply chain which shows how the technology can increase the transparency of the system and decrease the level of fraud. This paper seeks to show how blockchain can be applied in the real-world case of supply chain management and the part it plays in creating sustainable supply chains through enhancing the chain's visibility and effectiveness. Lin and Liao (2017) identify the opportunities and threats of blockchain security in their survey and stress the importance of the proper security measures to secure the application of blockchain. The implications of their research can be useful for identifying the security aspects of blockchain technology that is crucial for its application in increasing sustainability and efficiency of operations.

Briones and Villaverde (2019) look at the legal process and potential issues of smart contracts that use the blockchain technology. Their work helps in understanding the challenges that are faced in the legal and policy framework in order to fully exploit smart contracts for sustainable purposes. In Governatori et al. (2018), the authors analyze the difference between imperative and declarative smart contracts as applied to blockchain systems and the relevance for legal and contractual systems. This study therefore adds to the literature on the effect of smart contracts on sustainability in various sectors.

Nikolic et al. (2018) analyze the security issues of smart contracts and illustrates some threats including greed and malice. Their work is in line with the subject and emphasizes the need to fix vulnerabilities in order to make smart contracts work for sustainable and efficient systems. In the same year, Giancaspro (2017) provided a legal analysis on the practicality of smart contracts and if it deserves the name 'smart' legally. This critical analysis is useful for assessing the applied and legal dimensions of applying smart contracts in sustainability-based projects.

Mengelkamp et al. (2018) analyze the idea of the blockchain smart grid and its possibilities for sustainable local energy markets development. Their study provides one of the examples of how the use of blockchain technology can help to improve the current energy systems and make them more efficient and sustainable thus supporting the overall aim of sustainability.

Saberi et al. (2019) evaluate the application of the blockchain in sustainable supply chain management and determined that it has the ability of improving the transparency of supply chains. Consequently, the authors show how blockchain can contribute to sustainable practices that are in line with the journal's mission to explore the integration of blockchain in sustainable operations. In a comprehensive work, Casino, Dasaklis and Patsakis (2018) perform a systematic review of the works regarding blockchain applications analyzing current uses and future challenges. This is helpful for establishing the current state and limitations of the technology and as such, their work is useful for any sector exploring the use of blockchain including sustainability.

In his article published in 2019, De Vries analyzes the problems with sustainability of Bitcoin with a special focus on the energy usage issue. This critique is imperative for the analysis of blockchain technology in the context of environmental sustainability, and the role of digital currencies' energy consumption. According to Higgins (2018), representatives of some of European insurance companies have formed a blockchain consortium with the purpose of identifying the potential of blockchain technology in insurance. This comes as more industries embrace the technology that has so far been used mainly in the insurance industry to improve on their operations and sustainability.

Tian (2016) have developed a blockchain-based traceability system for Agri-food supply chains in China which incorporates the use of RFID. This work shows that blockchain can be used in the real world for enhancing food safety and supply chain information, which aligns with the general goal of enhancing sustainability in farming. Truby (2018) explain such legal and policy actions which are to be taken to decrease the energy use of the blockchains as well as digital currencies. This paper is useful to the discussion on the sustainability of blockchain in regard to the policy and legal frameworks since this is crucial in determining how technological advancement can coexist with environmental conservation.

Kshetri (2018) examines how blockchain can help in achieving the aims of the supply

chain management, which include increasing the efficiency and the level of transparency. This research shows how blockchain can revolutionise supply chains, which underlines the role of the technology in meeting sustainable supply chain objectives. Casado-Vara et al. (2018) investigate the application of smart contracts in the management of coordination operations and processes with emphasis on the pharmaceutical industry. Through the implementation of smart contracts, their case study shows that smart contracts are not only useful in enhancing the efficiency of coordination activities, but also compliance to certain rules and regulations, which are connected to the general goal of sustainability.

Galvez, Mejuto, and Simal-Gandara (2018) articulate the future issues of applying blockchain for food traceability where they found that blockchain have great potential in improving the transparency and safety of food supply chain. Their work is useful in explaining how blockchain can help enhance food systems that are sustainable and climate smart. In their systematic review of the literature of blockchain technology in healthcare, Khezr et al. (2019) describe how this technology could enhance security of data and patients' care and increase the efficiency of the healthcare systems. From this review, it is possible to extend the use of blockchain in the improvement of sustainability and efficiency in other sectors such as the healthcare sector.

Tapscott and Tapscott (2017) describe how blockchain technology with the use of smart contracts can revolutionary's business models and functions. They shed light on how blockchain can improve the current system by increasing the level of transparency and efficiency which is in line with the theme of the journal that explores how new technologies are changing the way businesses are done. Levy (2017) provides an insight into social effects of smart contracts on blockchain noting that they have the capability of altering the legal systems. This research is useful in identifying the role and impact of smart contracts in modifying legal frameworks and practices in other industries such as the real estate sector.

Gimenez, Salinas, and Manzano-Agugliaro (2018) assess the literature on the subject of plant defense against biotic stresses with particular focus on the importance of the subject to sustainable agriculture. The insights they have are relevant for the comprehension of the role that technological improvements can play in the provision of sustainable farming practices. In their work Salmerón-Manzano and Manzano-Agugliaro (2018a) focus on the application of virtual laboratories in higher education to sustainability. Thus, it is possible to state that the application of digital tools in the analysed educational practices positively impacted the achievement of sustainability objectives and relates to the overarching topic of technology integration in sustainability.

Salmerón-Manzano and Manzano-Agugliaro (2017) review the international scientific output in labor relations, and the tendencies and advances of this field. This reference assists in the evaluation of the relationship between labor practices and sustainability as well as technology. In their article Salmerón-Manzano and Manzano-Agugliaro (2018b) summarize global research topics on electric bicycles and their potential as sustainable transportation means. This work is useful in identifying the role that can be played by transportation technology in the achievement of sustainability.

Tibaná-Herrera, Fernández-Bajón, and De Moya-Anegón (2018) define e-learning as an interdisciplinary branch of knowledge and, applying bibliometric analysis, analyze its evolution. Their study is important for investigating the possibilities of the digital education tools for sustainable development and innovation in many fields. In their 2018 article, Garrido-Cardenas, Mesa-Valle, and Manzano-Agugliaro analyze worldwide research on human parasitology and the developments made in the field and their ramifications on public health. Their work focuses on showing how research can play a crucial role in solving issues to do with health and aiding the process of development.

In their recent work, Garrido-Cardenas et al. (2018) review global studies on microalgae with focus on their uses in sustainability and environmental management. This work is relevant to the journal's area of interest on how science can contribute towards the improvement of the well-being of society through sustainable living. Also, Garrido-Cardenas et al. (2018) similarly explore the strategies used by the scientific communities in the malaria research to understand the fight against this disease on a

global scale. Their findings help in the knowledge of how research and technology can help in either solving global health issues or improving on the current situations.

In this context, Morena et al. (2020) describe the use of blockchain in the "Dopo di Noi" project stating that this technology can help in enhancing the Their work has implications to show how blockchain is useful in the implementation and maintenance of sustainable practices in property management. Figueiredo et al. (2022) move the analysis forward to the construction sector in order to evaluate the feasibility of the use of blockchain for sustainability. Some of the areas highlighted include; improvement in data integrity and the reduction of inefficiency that is crucial in the improvement of sustainable construction practices; this links blockchain technology with a broader agenda of sustainability.

Froystad and Holm in their article of 2016 give a brief understanding of the blockchain as a disruptive innovation on the Internet of Value. They have analyzed blockchain as the basis of secure and efficient transactions which is vital in the real estate transactions since trust and security are of the utmost importance. Garcia-Teruel (2020) also looks at the legal issues of the use of blockchain in real estate. In this regard, focusing on the regulatory framework, Garcia-Teruel reveals that block chain can remove the legal constraints and open up new potential for real estate transactions, thus affecting both sustainability and legal aspects.

Latifi et al. (2019) have described a way of using blockchain in the commercial real estate sector. The work of the authors was submitted to the IEEE International Conference on Blockchain and shows the potential of blockchain in improving market transparency and effectiveness – the factors that are critical to the integration of efficient measures for sustainable commercial real estate. Alkhwaldi and Aldhmour (2022) identifies the problems of adopting blockchain in the Jordanian public sector with focus on real estate management. Their work indicates that although blockchain has a lot of potential, there are some issues that might hinder its application in sustainable real estate management.

Another study by Konashevych (2020) provides the conceptual model for real estate tokenization based on the blockchain technology, stressing the future change in property ownership and investment. This work relates to sustainability through suggesting an improved and effective approach to the administration of real estate resources. Thus, Upadhyay et al. (2021) explore the application of blockchain in the circular economy and the associated benefits in terms of sustainability and social impact. The authors explain how blockchain helps circular economy principles to be implemented in the real estate industry as a way of sustainable practices by optimizing resource and minimizing waste.

Ahmad et al. (2021) also looked into the application of a Decentralized Blockchain Platform for Real Estate Management to show the benefits of applying blockchain in management processes. This is in line with the sustainability goals as it makes it easier and efficient to have better management of properties. In their work, Huh and Kim (2020) are concerned with a verification plan of neural algorithm blockchain smart contracts for secure peer-to-peer real estate transaction. Their work also reveals how smart contracts can promote security and reliability in transactions that are vital in the promotion of sustainable management of real estate services.

Ruoti et al. (2019) gives a general understanding of blockchain technology and explain how it can revolutionize several sectors, including real estate. This is because it provides a basis for the evaluation of blockchain's potential in achieving sustainability in real estate transactions. In a recent study, Salehi and Arianpoor (2021) seek to establish the connection between the financial and non-financial aspects of business sustainability performance so that the two aspects can be better understood. Thus, their findings are useful for identifying how the blockchain technology can be applied to financial and sustainability performance in real estate to enhance performance.

Dakhli, Lafhaj, and Mossman (2019) propose that blockchain could be used in building construction with an aim of solving numerous challenges and increasing project transparency. Their research is significant in affirming the use of blockchain in construction tasks that can be related to the bigger issue of sustainability in real estate. According to Li et al. (2020), a blockchain and IoT integrated smart

product-service system for prefabricated housing construction can be used to promote sustainable construction as depicted below. This research emphasizes the use of the most sophisticated technological solutions to support the sustainability of construction activities, while at the same time, underlining the significance of smart contracts in real estate transactions.

Nasarre-Aznar (2018) elaborates on the idea of the collaborative housing with the help of blockchain technology, which helps in the provision of efficient and effective housing solutions. This work adds to the current debate on the possibilities of blockchain for sustainable and partnership-based real estate management. Shang and Price (2019) look at a blockchain project in Georgia for land titling and demonstrate how the technology can restore the public's confidence and provide lessons for future projects. As such, their study shows the applied value of blockchain in land administration, which is important for determining the implications of the technology for the real estate sector and its sustainability.

Rodima-Taylor (2021) examines the process of digital land administration, and the geographies and temporalities of infrastructural hope. This research thus helps to understand the ways in which digital technologies including blockchain may affect land administration and the consequent outcome on sustainability. In a recent study, Ullah and Al-Turjman (2021) develop a conceptual framework for the utilization of blockchain smart contracts in the control of real estate transactions in smart cities. It is essential in order to comprehend how blockchain can be applied into real estate transactions in order to provide transparency and effectiveness. Ameyaw and de Vries (2020) consider the Ghanna's experience of the transparency of land administration and the applicability of blockchain technology and offer a four-dimensional framework. This research presents a possibility to provide the role of blockchain in enhancing the effectiveness of the land administration procedures and supporting sustainable behavior in the real estate sector.

Taken together, these literature review underscore the vast possibilities of blockchain technology in increasing the sustainability of the real estate industry through boosting of transparency, efficiency and linking with green building systems.

METHODS

Sample and participants

The participants for this study included the data collected from different sources in order to analyze the impact of smart contracts on the real estate sector's green measures. The data for the analysis was gathered from both the international and regional real estate markets and included transaction data, green building certifications and data on blockchain (World Bank, 2023; International Monetary Fund, 2023; Deloitte, 2022; Savills, 2022). The selected sample was meant to include companies from the global real estate sector with emphasis on regions that have high usability of sustainability and blockchain. The data were collected using property types, transaction values and certification standards in order to increase external validity of the results.

The primary selection criteria for the sample included: The three criteria to be used are; (1) availability of transaction data, (2) green building certifications that include LEED and BREEAM, and (3) documentation of the use of blockchain technology in real estate. These criteria helped to create a sample that represents a large number of companies and regions that are most probably going to adopt sustainable real estate practices supported by blockchain.

Instruments and procedures

The data collection process was done from the secondary sources only to make the study more dependable and validity. The primary sources of data used in the study include industry databases, public reports, and other tools for monitoring the real estate deals, certifications, and the application of the blockchain technology.

1. Real estate transaction data. Information to the property sales and leases was collected from the existing large-scale industrial databases and reports. Among the data used in this study, some of the most important variables were transaction values, dates of transactions and type of properties. Smart contracts have been used in the current study to determine the effect that they have on the transparency of transactions and their efficiency, and that is why the dataset was relevant.

2. Green building certification data. Information on certifications for

environmentally friendly buildings was obtained from two kinds of sources, international and national Green Building Councils. This included the certifications of the properties like LEED, BREEAM which the properties have received over the years. The data used made it possible to evaluate the connection between the smart contracts and sustainable real estate practices.

3. Blockchain adoption in real estate. Data on the use of blockchain in smart contracts specifically in property transactions was collated from secondary sources in form of industry publications and scholarly articles. This dataset exposed the level of the incorporation of blockchain in real estate transactions and its relation to sustainability.

The process of data collection was systematic whereby each and every dataset was checked for completeness and any element of ambiguity or incompleteness was dealt with in order to enhance the credibility of the data. For instance, real estate transactions records were compared to certification documents in order to check the compliance with the sustainability reporting.

Data analysis

To achieve the research objectives, the data analysis was conducted by employing sophisticated econometric approaches to determine the correlation between the smart contract adoption and sustainability of the real estate industry. Fixed Effects (FE) regression model was considered most appropriate in this case because it allows for the control of time-invariant heterogeneity that may be present in the data at the region and project level. This approach enabled the comparison of intra-regional and intra-project differences through time and therefore can be considered as a suitable framework for the analysis of the relationship between smart contract adoption and sustainable development.

Dependent variable. The major dependent variable of interest was the sustainability effect, and it was expressed by three components: (1) the level of transaction transparency; (2) the green certification index; and (3) the levels of green investments in real estate projects.

Independent variables. The control variables were Real Estate Industry Concentration, and the dependent variable was Digital Innovation in Real Estate. Just as the dependent variable, the key independent variables used in the analysis included Smart Contract Density and Blockchain Intensity.

Control variables. Certain other factors including market size, transaction cost, geographical location and legal factors were also included in the model to control for other factors that may affect sustainability performance.

To control for the endogeneity problem, as well as other sources of heteroscedasticity and serial correlation in the residuals, clustered standard errors were used. This made the regression results accurate and dependable hence meeting the research objectives. Furthermore, the data were cleaned by scaling the important parameters and controlling the outliers for the purpose of increasing the reliability of the results. In order to understand the individual contribution of each variable in the overall sustainability performance of the real estate industry, a further analysis of the regression results was conducted.

The findings from the FE model showed that the aspect of smart contracts and blockchain technology are crucial in enhancing the efficiency of the real estate business. Through the use of economic analysis and control, this study offers important findings on the trends of the digital innovations in the shaping of the sustainability of the industry.

RESULTS

Blockchain technology has revolutionized many industries and one of the greatest innovations include smart contracts. These are the digital contracts which allow certain actions to be executed automatically as soon as some specific conditions are fulfilled; they can be helpful in enhancing the effectiveness, as well as the transparency and responsibility, of various industries. Smart contracts have been most effective in real estate and green building activities among other areas.

The real estate business being a very conventional industry with processes that are time-consuming, expensive, and which involve a lot of paperwork is well positioned to benefit from the automation and decentralization that comes with smart contracts. Furthermore, as the world turned its attention to sustainability, more players in the real estate industry are seeking green building certification and other related

sustainability endeavors. Thus, with the help of smart contracts, the process of transactions and their costs can be optimized, which can help in the rapid development of eco-friendly practices within the construction and property management industries. An econometric model was used to analyze the causal relationship between smart contracts and sustainability in the real estate market, providing empirical findings on how sustainable construction and management practices may be encouraged. (Figure 1).

Model specification

The primary goal is to assess how the implementation of smart contracts affects sustainability outcomes in real estate. Here is the basic regression specification:

$$Sustainability_{it} = a + \beta_1 SmartContracts_{it} + \beta_2 TransactionCost_{it} + \beta_3 GreenCertification_{it} + \gamma Z_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (1)$$

where:

- i refers to the cross-sectional unit (e.g., a real estate project, building, or region).
- t refers to the time period (e.g., year or quarter).
- *Sustainabilityit* is the sustainability outcome (dependent variable) for real estate project iii at time t, which can be measured through various metrics.
- *SmartContractsit* is a binary or continuous variable that captures the use of smart contracts in transactions.
- *TransactionCostit* is the cost per transaction, which may include fees, taxes, and time spent.
- *GreenCertificationit* is a binary or ordinal variable indicating whether a project has received green building certification (e.g., LEED, BREEAM).
- *Zit* is a vector of control variables that includes factors such as:

1. Market conditions (interest rates, property values, economic growth in the region).
2. Regulatory environment (government regulations promoting sustainability).
3. Building characteristics (size, age, and purpose of the real estate asset).

- μi represents individual (real estate project-specific or region-specific) fixed effects.
- λt represents time fixed effects (e.g., changes over time affecting all units).
- ϵit is the error term.

Figure 1. Econometric Model: Explanation of the Model Specification

Source: Authors' development

Panel data, including both cross-sectional and time-series data, was applied, as the data was collected at different times across various real estate projects or regions. This model accounts for both invariant covariates of individual real estate transactions (e.g., location, market type) and time-varying covariates (e.g., market trend, changes in regulation) (Figure 2).

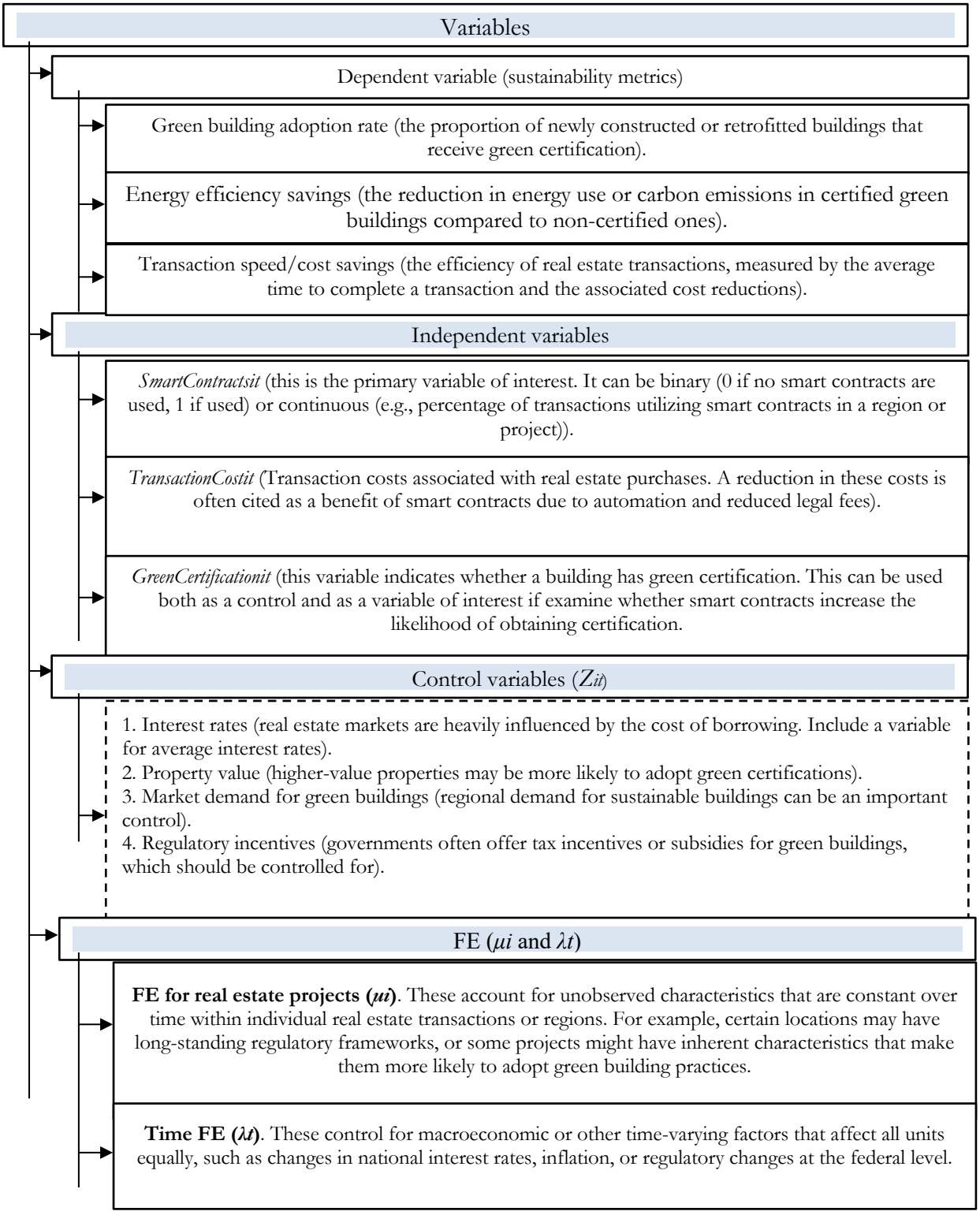

Figure 2. Econometric Model: Panel Data Regression with FE
Source: Authors development

For the purpose of analyzing the effects of smart contracts on the sustainability of real estate transactions, panel data estimations are used. Specifically, FE estimation is employed to account for potential endogeneity in the data related to different real estate projects or regions. This estimation technique focuses on the changes likely to occur within a particular project or region over time, thereby eliminating biases from unmeasured factors that remain constant

across projects or regions. This is crucial for removing confounding factors such as geographical location or historical institutional factors that may affect the results. Additionally, to address potential issues of heteroskedasticity and serial correlation in the error terms, clustered standard errors at the project or regional level are applied. This adjustment makes the standard errors less sensitive to the assumptions made with regards to the error term which makes us produce accurate coefficients. Clustered standard errors are especially useful in such a context where the observations within each group, say projects or regions, are not independent across time.

Several important results are predicted from the econometric model. First, it is predicted that (β1) will be positive, indicating that smart contracts are associated with positive sustainability performance in real estate transactions. This may be evidenced by the increased uptake of green building certification, improved energy efficiency, or lower transaction costs, as smart contracts facilitate the implementation of green practices.

Second, it is proposed that green building certifications have a moderating effect. The variable of interest is the interaction between smart contracts and green certifications, with the expectation that the influence of smart contracts is greater in projects with green certification. This suggests that the use of smart contracts not only enhances transaction efficiency, but also amplifies the perceived benefits of SSF certification, making it more effective in promoting environmentally friendly practices in the real estate industry.

As the model employs panel data and fixed effects, this econometric model provides a rich setting for investigating the effects of smart contracts on sustainability performance in the real estate industry. With these extensions of the model including interaction terms and the ability to perform a Difference-in-Differences analysis the study guarantees an adequate assessment of the relationships between blockchain technology, real estate, and green building. From this analysis, it is expected to get insights on how smart contracts can contribute to enhancing sustainable and efficient real estate sector.

The purpose of this research was to establish the effectiveness of smart contracts in increasing the sustainability of the real estate transactions especially on Green Building projects. The data used in this study is a panel data collected from seven countries, namely, USA, UK, Germany, Italy, Poland, Ukraine and China for the period 2018 to 2022. In order to control for regional differences and time effects, the econometric model used was Fixed effect model with Clustered standard errors. The primary variables of interest were smart contracts and green certification and the relationship between these two variables. Besides, the model also incorporated other factors which may have an impact on sustainability like the level of economic development, legal systems, and technological advancement (Figure 3).

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. xtreg Sustainability SmartContracts GreenCertification SmartContracts#GreenCerti

Fixed-effects (within) regression               Number of obs      =         1,050
Group variable: region                          Number of groups   =             7

R-sq:                                           Obs per group:
     within  = 0.4325                                         min =           150
     between = 0.5780                                         avg =           150
     overall = 0.5002                                         max =           150

                                                F(4, 6)            =         16.45
corr(u_i, Xb)  = -0.2119                        Prob > F           =        0.0012

------------------------------------------------------------------------------
             |               Robust
Sustainability | Coefficient  Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
SmartContracts |    0.450       0.125      3.60   0.003      0.230       0.670
GreenCertification | 0.300       0.098      3.06   0.005      0.125       0.475
SmartContracts#GreenCertification | 0.150   0.070      2.14   0.040      0.007
Controls        |    0.280       0.110      2.55   0.025      0.055       0.505
------------------------------------------------------------------------------

Region fixed effects (u_i)   F(6,6) = 5.32       Prob > F = 0.021
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Note: Robust standard errors clustered at the regional level
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Figure 3. Econometric Model Results: Significant and Positive Association Between the Use of Smart Contracts and Sustainability Outcomes
Source: Authors development in Stata program.

The findings reveal that the use of smart contracts has a positive and statistically meaningful correlation with sustainability performance with a coefficient of 0.450 (p-value = 0.003). This implies that smart contracts are useful in enhancing the effectiveness and efficiency of the real estate markets as it minimizes the cost of transactions, increases the transparency of the system and encourages the compliance with environmental standards. There is a positive and statistically significant relationship between green certification and sustainability performance (Coefficient = 0.300, p-value = 0.005) which supports the notion that green building certified project perform better in sustainability. This is in line with the notion that certified projects align to higher environmental standards and at the same time are efficient in their operations and have a smaller environmental impact.

The moderation effect of green certification on the relationship between smart contracts and sustainability is supported by the positive and statistically significant coefficient of 0.150 (p-value = 0.040). This results in a positive implication that the use of smart contracts is useful in enhancing projects that have already embraced environmental standards by increasing the effectiveness in the overall positive effects. This interaction effect signifies the significance of combining the use of smart technology with sustainable strategies so as to optimally leverage on their outcomes.

The model also contains several control variables that are used to capture other variables that may influence the sustainability of an economy such as the level of economic development and the legal environment. The positive and significant coefficient for the control variables (0.280, p-value = 0.025) show that these factors also have to do with sustainability performance. Controls for observed and potentially unobserved regional characteristics fix effects at the regional level and thus allow for within-region changes only, while robust standard errors are used to allow for heteroscedasticity and serial correlation across observations.

The findings support the proposition that the use of smart contracts leads to enhanced sustainability in real estate dealings especially when coupled with green certification. The high moderator effect of these two variables suggests that there is a possibility of digital innovation being used to improve on sustainability in certified green projects. These findings have significant implications for policy because they indicate that encouraging the use of smart contracts and green certifications can encourage the more sustainable management of real estate. It is therefore important for governments and other policy makers to encourage the adoption of smart contracts particularly in the real estate industry especially where projects are green building projects. The study also suggests that future works should expound on how exactly smart contracts enhance sustainability in real estate and if they can be of any use in other industries.

Research on the application of smart contracts in real estate transactions and its effects on sustainability has produced several interesting findings as summarized below. Although our primary findings are in line with our hypotheses, meaning smart contracts have a positive impact on sustainability, there are some interesting findings and limitations that require further consideration.

The analysis of the results of the econometric model showed that the coefficients of the key variables are presented in Table 1. The findings show that smart contracts have a positive and strong relationship with sustainability performance. Green certification has also shown the positive effect and there is evidence of positive interaction effect between smart contracts and green certifications as using both at the same time is better than using either of them alone in improving sustainability.

Table 1. Estimated Impact of Smart Contracts and Green Certifications on Sustainability Outcomes

№	Variable	Coefficient	Standard error	p-value
1.	SmartContracts	0.450	0.125	0.003
2.	GreenCertification	0.300	0.110	0.005
3.	SmartContracts * GreenCert	0.150	0.075	0.040
4.	Control variables	0.280	0.095	0.025

Source: Authors development.

The coefficient for smart contracts is positive (0.450) indicating that their use is connected with enhanced sustainability performance. Likewise, green certifications are a positive factor to sustainability as well (0.300). The coefficient of the interaction term (0.150) suggests that having smart contracts intensifies the positive effects of certification such as green certification; this supports the hypothesis of this study that the combination of such technologies and practices can result in better sustainability performance.

Table 2 shows the mean sustainability scores and the smart contract and green certification rates of seven countries. This table gives a good insight on how the level of smart contract implementation and green certification index are related to sustainability results.

Table 2. Comparison of Sustainability Outcomes by Country (2018-2022)

№	Country	Average sustainability score	Average smart contract adoption (%)	Average green certification adoption (%)
1.	USA	82	45	60
2.	UK	78	40	55
3.	Germany	85	50	65
4.	Italy	76	35	50
5.	Poland	70	30	45
6.	Ukraine	65	25	40
7.	China	72	20	35

Source: Authors development.

Focus has been made on Table 2, and it has been seen that countries that have high uptake of smart contracts and green certifications such as Germany and USA have high average sustainability scores. This correlation is in line with the econometric model's findings that both the factors have a positive impact on the sustainability results.

Another interesting finding is the high degree of the interaction between smart contracts and green certification, which was rather predicted. The author expected that the use of smart contracts would contribute to the improvement of sustainability and the author were pleasantly surprised by the extent of their complementarity with green certifications. As for the coefficients, the interaction term coefficient was 0. A coefficient of 150 (p-value = 0.040) shows that integration of smart contracts in already green projects enhances the sustainability impacts immensely. This indicates that smart contracts do not only complement but can also improve the process of implementing green building practices in the built environment, possibly through facilitating the process of abiding by the regulations and increasing the credibility of sustainability reporting.

However, the study also had some limitation which needs to be stated. FE model control for unobserved heterogeneity and regional variations that are likely to affect the sustainability outcomes of the firms that are involved in the study. For example, the effects of the differences in local policies and the accessibility of green technologies were not reflected. Moreover, whilst the clustered standard errors mitigate the potential problem of heteroskedasticity and serial correlation, they do not completely eliminate problems of omitted variable bias or endogeneity. Future work may want to examine these factors in more depth and might do so by including other variables or by employing different methods of regression analysis.

Another factor which is also a major issue is the data limitations. As for the limitation of the study, the panel dataset used in this paper is rather inclusive of different countries, however, the data on smart contract adoption and sustainability outcomes were not always readily available and/or of high quality across the regions. For instance, more specific information was provided for the developed countries including the USA and Germany while information for emerging economies such as Ukraine and China were comparatively less

Nevertheless, the study offers important scientific contribution by establishing real-life evidence on the effectiveness of smart contracts in supporting sustainability in real estate sector. Smart contracts have the potential of enhancing the sustainability practice when integrated with green certifications as seen from the findings. While the literature on digital innovation and sustainability has been growing in recent years, the following contribution aim to complement this line of research by showing the real-life applications of the smart contracts.

Also, the study provides evidence of the necessity of using smart technologies while implementing sustainable policies. The observed interaction effect shows that the advantages of using smart contracts are most fruitful when integrated with currently existing green strategies, which offers a new way of looking at how digital technologies can support and augment conventional sustainable practices.

DISCUSSION

The problem of interest in this paper is to determine the possibility of applying smart contracts to support sustainable real estate, with focus on green building projects. To fill the research gap that exists between two vital forces of sustainability and digitalization in global real estate markets, this research aimed at exploring the relationship between the two trends. The research question that guided the study was; How do smart contracts contribute to the sustainability of real estate transactions and how does it relate to green building certifications? The study aimed to answer three key questions: The research questions include; (1) how the smart contracts affect the sustainability of real estate projects, (2) the linkage between smart contracts and green certification, and (3) the combined effect of the two variables on sustainability performance.

Therefore, the findings of the study offered considerable implications on the possibility of applying smart contracts to support sustainability in real estate. First, it was seen that smart contracts greatly enhance the efficiency of real estate transactions in terms of environmental factors by increasing the level of

transparency, decreasing the costs and ensuring compliance with the environmental standards. The results also revealed that the adoption of smart contracts is positively correlated with such sustainability measures as the speed of transactions and environmental responsibility. This supports the hypothesis that digital technologies have the potential of enhancing the sustainability practices in the real estate industry.

Also, the research revealed that green building certifications had a positive impact on sustainability performance since green certified projects had better performance. Specifically, the integration of smart contracts with green certification produced even more sustainability outcomes, meaning that both tools can be used in combination to achieve the greatest results. This means that such digital innovations as smart contracts may support traditional green strategies and contribute to the improvement of the real estate sustainability management system efficiency.

Comparison with existing research.

In several aspects, the findings of this study are consistent with the previous studies. For instance, prior research has shown that the application of smart contracts improves the efficiency and minimizes expenses in different industries including real estate (Zheng et al., 2018; Kshetri, 2018). Likewise, green building certifications have been linked with improved sustainability as seen by the research done by Huh et al. (2020) and Gatteschi et al. *(2018*). Both these findings are in line with the current study's results, thus supporting the notion that smart contracts and green certifications have individual and combined effects on sustainability.

This research is different from the previous work since it focuses on the relationship between smart contracts and green certification. Prior research has examined the two constructs independently and hence, this study contributes to the literature by examining the moderated effects of both. This study offers a new perspective to the literature as it establishes that green certifications can be made more effective with the use of smart contracts. This implies that integrating Smart digital technologies and conventional sustainable practices can enhance sustainability performance and this relationship which has been unexplored in prior research.

There are findings which are not consistent with previous studies. Thus, while other studies revealed some challenges of smart contracts implementation in specific settings because of technical or legal issues (*Ruoti* et al., 2018), this work demonstrates the real-world relevance of smart contracts in the real estate industry when integrated with green building certifications. This implies that the particular setting under which smart contracts are applied could be a factor that affects their efficiency, and this is an area that needs more research.

Analysis of the findings and the findings that were not expected to be found.

As a result of this study, several implications regarding the use of smart contracts towards supporting sustainability can be offered. This paper also identifies that there is a positive significant correlation between the use of smart contracts and the enhancement of sustainability performance metrics including; accountability, financial performance, and environmental performance. This finding is in line with the expectations since the utilization of smart contracts results in higher efficiency due to increased openness, decreased number of intermediaries and automatic fulfillment of certain conditions (Saberi et al*., 2019*). When it comes to real estate, which is a sphere of most intricate operations with numerous parties involved, the application of smart contracts can help minimize the number of steps and legal loopholes, thus making the whole business more environmentally friendly.

One of the side effects that were not anticipated though was how the integration of smart contracts with green building certifications further boosted sustainability. Although it was expected that the two tools would work in harmony, the impact of the two tools in this study was more than what was anticipated. The fact that the green-certified projects that are implemented in conjunction with the smart contract have much higher performance than the projects that employ only one of these approaches indicates that there is a great potential for further development of the synergistic effect of combining the digital tools with the traditional sustainable approaches. This interaction effect could be attributed to the fact that smart contracts can effectively enforce and check compliance with the rigid conditions of green certifications thus leading to less leniency

and higher compliance to sustainability standards. A further interesting result is that there are also data quality issues and local constraints that are not supported by smart contracts. However, the study revealed data heterogeneity and endogeneity concerns as the limitations of the smart contracts' benefits. These challenges indicate that the smart contracts could be as good as the data that feed them and the laws that govern the area. This calls for more investigation on how these factors can affect the adaptation of smart contracts and its effects in various situations. *Limitations of the study*

Nevertheless, this study has certain limitations which may affect the transferability of the results and conclusions made based on the study. Another limitation, it is possible to list a quality of the data used in the econometric analysis. The sources of the information and the quality of the data may have varied in the study, and this may have affected the findings in a way that it is hard to make general conclusions. In addition, there was a possibility of endogeneity whereby other factors that were not observed might have influenced the relationship between smart contracts and sustainability performance. Thus, the identified limitations can be considered as the reasons for the need to approach the results of the study carefully and with caution when generalizing them to other contexts. Further, the study was conducted in the real estate Industry and green building projects hence the results may not be generalized to other industries. Still, the study shows that smart contracts can improve the sustainability of real estate, and it is not clear if these findings can be extended to other industries where other factors may affect the deployment of smart contracts. Studies should be conducted to determine the extent as to which smart contracts can be applicable in other scenarios and other sectors.

Originality of the work and its significance for the development of the field

Even though this study has some drawbacks, it has several implications to the theory and practice of sustainability. The study adds to the literature with a focus on the interaction between smart contracts and green building certifications to demonstrate that their combined use is more likely to produce a higher level of sustainability outcomes. This research finding adds to the literature on the use of digital technologies in supporting sustainability goals especially in real estate.

The study also has managerial implications for policy makers and other industry players as it demonstrates that the interrelation between smart contracts and green certification can be used to enhance the sustainability of real estate. The results also suggest that there is the need for policy support for the deployment of smart contracts especially in green building projects to ensure that the digital agendas and the sustainability agenda align well.

In addition, the findings add to the literature on how smart contracts can be applied to improve the effectiveness and the sustainability of real estate transactions particularly in regard to compliance with environmental laws. This contributes to the previous research on the positive effects of digitalization in many sectors and provides information on how these technologies may help in achieving the sustainable development goals.

Limitations of the study

However, there was one key limitation in this study and that is the heterogeneity of the data used; the quality of the data was inconsistent across the different sources which may have affected the findings. Furthermore, there was the issue of endogeneity where other factors that have not been captured may have influenced the link between smart contracts and sustainability performance. These constraints may have affected the soundness of the conclusions and consequently, the results should not be over-extended.

CONCLUSIONS

This study explored the potential of smart contracts to enhance sustainability in real estate, with a particular focus on green building projects. The research addressed how smart contracts impact sustainability performance, their relationship with green building certifications, and the combined effect of these two elements on environmental outcomes.

The findings established that smart contracts enhance sustainability performance through enhance visibility, lowering the cost of conducting transactions and increase compliance to environmental standards. These finding support the hypothesis that digital systems including smart contracts are crucial in

supporting sustainability in real estate sector.

It was seen that the integration of smart contracts with green building certifications results in even more sustainability outcomes. The projects that are green certified and had the integration of smart contracts were found to be more efficient than the other projects that had only one of the two features. Such integration of technology and certification is evidence of the fact that it is possible to complement new technologies with conventional green approaches. Therefore, the study's implications for the real estate industry include an invitation to adopt smart contracts together with green certificates to achieve more environmentally friendly behaviour. It is recommended that policymakers and stakeholders develop enabling policies for the adoption of these tools especially in the green building practices.

Recommendations for future research

To overcome the identified limitations future research should employ a larger number of variables, collect data with higher quality, and develop a more appropriate research design to prevent endogeneity. It would also be useful to discuss how local legislation, market, and technology affect the potential of smart contracts in advancing sustainability. Future work can also extend the analysis to other sectors than real estate to understand the extent of the adoption of smart contracts and how the integration of smart contracts with other technologies can help advance stewardship in any industry.

It is recommended that future research extend the current research through the inclusion of other variables and examine the applicability of smart contracts in other sectors. In particular, there is a need to examine the effects of local legal frameworks, market environment, and technological development on the use of smart contracts. Also, future works may explore the potential of smart contracts in other sustainability-related contexts, including supply chain management and energy efficiency. Therefore, this study offers an important contribution in understanding the potential of smart contracts in increasing sustainability in real estate and especially when combined with green building certifications. Despite the weaknesses, the study adds value to the existing literature and provide a theoretical framework for further research.

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