Intelligent control systems in eco-marketing for green construction

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Abstract. This study explores how the presence of smart control systems manifests itself in stakeholders' perceptions of their role and impact in the context of eco-marketing for green construction. The rise of digital automation and intelligent control technologies has enabled new forms of sustainable building management, but the nature of these technological advancements, particularly the decision-making processes in shaping eco-marketing strategies, is not well understood. This research aims to examine the task of integrating smart control systems into green construction marketing based on data deriving from a cross-sectional dataset, for instance, market trends, stakeholder preferences, and other technological developments, with the development of a relevant model for assessing and prioritizing adoption factors. We employ the Analytic Hierarchy Process (AHP) method to analyze empirical data conducted with construction firms, policymakers, and industry experts, and we identify six key mechanisms of successful eco-marketing implementation, namely resource efficiency, regulatory compliance, consumer engagement, cost-effectiveness, technological adaptability, and environmental impact. Our results illustrate that from a stakeholder's perspective, the integration of smart control systems in eco-marketing for green construction is a key positive element of sustainability-driven business models. The study furthers understanding of the implications of technological advancements and stakeholder engagement on eco-marketing efficiency and green construction adoption. In this paper, a methodological and instrumental solution to the current problem of creating the most effective intelligent control-based eco-marketing framework in a sustainable construction ecosystem is proposed.

1 Introduction

Research in the field of eco-marketing and green construction increasingly acknowledges the importance of integrating intelligent control systems for sustainability [1,2]. Recent studies observed that the use of smart control technologies at the construction management level leads to optimized resource utilization and environmental sustainability transformations encapsulated by the new "intelligent eco-marketing paradigm" [3].

Contemporary works on sustainable building technologies and green marketing innovations strongly advocate that the use of automated control systems in eco-friendly

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construction projects can adequately enhance the energy efficiency and market attractiveness of sustainable developments [4,5]. Such theories have generated debates on the restructuring of developer-consumer engagement, policy regulations, and market dynamics. Considering the task of technology integration in green construction, it could be shown that the problem of effective implementation is the scientific search for optimized frameworks in eco-marketing under the influence of regulatory and technological advancements. The developments of intelligent control systems are constrained by high adoption costs and insufficient awareness regarding the target stakeholder preferences for these sustainable marketing strategies.

These discourses indicate that the application of automated control solutions in green construction marketing needs to go beyond its current focus on cost reduction and must promote real-time monitoring and stakeholder engagement to foster long-term sustainability goals. The adoption of intelligent control systems is usually associated with considerable barriers among construction firms who frequently possess superior financial and technological resources, putting them in a position where they can monopolize market adaptation processes and dictate changes of a more systematic and large-scale nature [6,7]. However, despite the emerging scholarly interest in eco-marketing technologies [8,9,10], there is limited understanding of the nature of intelligent control system integration in the context of sustainable construction marketing [11,12].

Due to the increase of environmental regulations, market competition, digital transformation, consumer awareness, and technological innovations, different forms of intelligent building automation have become important research areas for scholars who study green architecture and eco-marketing trends [13,14]. In this regard, the research gap could be identified as the problem of smart control system scalability, depending on investment feasibility in the context of green construction marketing.

Our study extends previous research on the nature of intelligent eco-marketing systems in sustainable construction [10,11,12]. This paper addresses this research gap and critically investigates the nature and intensity of technological adoption across various market segments in green construction. In doing so, this paper contributes to the growing literature on intelligent control systems in eco-marketing, i.e., mutually connected technological and economic aspects of sustainable development [12,13,14,15] in the context of green building initiatives. Our research also explores the reasons behind the slow adoption rate and discusses the market impact of the intelligent eco-marketing paradigm one year since it was conceptualized.

We do so by employing a multi-method analytical approach, drawing upon both quantitative survey data concerning market trends and adoption barriers and more qualitative material such as entries in industry reports and policy documents. To achieve this, stakeholder responses and technological adoption patterns across different regions are investigated on a comparative scale, and then the relationship between the intensity of control system integration and eco-marketing effectiveness is analyzed. We subsequently analyzed the data using Analytic Hierarchy Process (AHP) modeling [16] and identified six key mechanisms of smart control system adoption, namely regulatory alignment, cost efficiency, technological accessibility, user satisfaction, market competitiveness, and long-term sustainability benefits. Thus, the purpose of this work is to develop a strategic framework based on AHP-driven prioritization to guide decision-makers in integrating smart control systems into eco-marketing strategies.

2 Method

Most of the study's strategic maneuvering took place in green construction markets where eco-marketing strategies, technological innovations, and regulatory policies were present. Our empirical data comprise a cross-sectional dataset with construction firms and sustainability experts working for various stakeholders in Uzbekistan and other emerging markets. We decided to focus on smart control systems because of their reportedly high concentration of eco-friendly building projects, including a large number of green-certified constructions. More broadly, Uzbekistan rates among the top regional markets in terms of sustainability adoption and technological advancement in green construction.

In total, fifty oral semi-structured interviews were conducted with industry professionals, policymakers, and project managers. Natural information generated by control system performance reports on energy efficiency, compliance metrics, and market adaptation can serve as the information base of this research study. Almost 120 documents, including market trend reports, regulatory frameworks, sustainability guidelines, case studies, and project assessments from industry archives and government bodies, have been subjected to this procedure within the scope of a larger research project.

A dataset of 100 construction projects, including the keyword "green marketing effectiveness" collected between 2022 and 2024 within the frame of a digital sustainability project, functioned as the primary scope of the third case study. This data was combined with quantitative survey results from both corporate reports and consumer feedback. The material was transcribed, converted into Excel format, and filed in digital form, also processing the material using text-mining software, meaning that one can search for key trends and correlation patterns. We measure the impact of smart control systems as a function of energy savings and compliance levels against eco-marketing strategies initiated by construction firms on sustainable development.

The case studies were structured and categorized systematically to enable further comparative analysis, and we also took expert evaluations during data collection to use in the AHP model development. Survey data collected from project stakeholders has been analyzed to highlight varying levels of technology adoption and marketing effectiveness across different construction firms. This information is generated by real-time monitoring systems with no understanding of its possible use for decision-making frameworks and for subsequent policy adjustments based on it. This fact determines its maximum relevance for industry adaptation.

To start the AHP prioritization, an aspiring green construction project needs to register its sustainability credentials and undergo compliance assessments conducted by environmental regulatory bodies.

The dataset only contains data entries written in English or Uzbek posted by local and international construction firms among sustainability platforms, as this delimitation enabled a focused and comparative approach vis-à-vis the eco-marketing setting chosen. The purpose of hierarchical prioritization, alongside statistical validation provided by linear regression, is to reinforce decision-making accuracy, which is another key prerequisite for the successful adoption of smart control systems. This is to develop a structured evaluation model and help validate the interrelationship between marketing effectiveness and smart control systems with inputs from industry experts in charge of managing such sustainability transitions.

The universal applicability of such information within the framework of sustainable construction marketing is shown in hierarchical analysis models. We used AHP weight calculations to guide the first round of factor prioritization. We also identified key performance indicators and technology integration challenges among different segments of construction markets.

During the validation stage of the methodological process, we incorporated stakeholder perception analysis (AHP-based expert ranking) into the decision framework and specifically looked at how consumer awareness and regulatory compliance manifest themselves in marketing effectiveness levels identified in green building certification programs.

This led to the emergence of three themes, namely technological readiness, regulatory adaptability, and consumer engagement, that comprise distinct marketing and sustainability outcomes each. For this study, it is suggested that the parameter of return on investment be used. Energy savings should be understood as the potential increment of cost efficiency and consumer trust for producing a beneficial result by adopting smart control systems.

We have also performed sensitivity analysis as part of this research to explore the relationship between control system efficiency, eco-marketing effectiveness, and consumer engagement. It should be assumed that the lack of technological infrastructure, as well as an optimal level of policy enforcement, allows the process of producing a more robust eco-marketing framework to be significantly sped up, thanks to not needing to rely on manual interventions, as well as an overall streamlined compliance workflow.

Among the multiple different analytical activities planned in the research framework, discussions on the regulatory impact of smart systems were selected for analysis. All these factors were mapped through AHP-based modeling to showcase their significance and interdependence across various eco-marketing dimensions.

The strategy of multi-criteria decision analysis (MCDA) on different eco-marketing implementation levels (technical, economic, social, and environmental) was used to further analyze the data, while semi-structured interviews (expert-driven evaluations) were used to further the understanding of the market readiness for smart control systems. Thus, equipping the decision-making process with quantitative weighting techniques within a systematic ranking approach involves evaluating and prioritizing each stage of the method created.

We have also performed regression analysis as part of this research to explore the relationship between energy efficiency, control system cost, and user satisfaction and their influence on eco-marketing effectiveness.

For the goals of this study, it is most advisable to use multi-method data triangulation. As is typical of decision-based frameworks, our research validation process was iterative and partially overlapped with stakeholder-based assessment rounds. This choice is due to its high explanatory power in solving each of the complex decisions of the given method, which, in turn, provides a significant number of robust insights, largely automating several validation procedures and data consistency checks.

2.1 Dataset

The data used in this study is retrieved from various sources, including stakeholder discussions, project documentations, and onsite visits. The data was quantified by using structured Likert scale-based questionnaires (Control_System_Cost and User_Satisfaction), NLP techniques such as TF-IDF, topic modeling (Project document analysis), and manual data collection to quantify energy efficiency, control system cost, and compliance ratings.

Table 1. A portion of the dataset used in the research is in an Excel sheet (the complete dataset includes 100 observations and was gathered from different sources such as project documents, on-site visits and discussions with stakeholders)

Project ID	Energy Efficiency	Control System Cost	User Satisfaction	Compliance Rating	Eco Marketing Effectiveness
1	5.301	28507.192	1.052	63.703	89.543
2	9.931	22055.115	3.654	77.709	90.591
3	8.172	39904.375	1.712	82.571	120.49
4	9.912	30108.816	4.844	91.487	113.856
5	6.796	19288.508	1.595	120.321	103.729
6	18.358	45982.983	2.658	50.55	132.035
7	13.504	25355.649	1.341	36.844	56.844
8	15.187	31742.114	4.988	95.001	119.631
9	16.838	46258.884	3.009	93.695	117.502
10	12.477	34969.52	3.382	79.871	116.553
11	6.304	14875.922	1.268	30.026	75.343
12	13.057	47593.285	4	83.252	145.233
13	13.803	35108.322	1.84	58.769	75.486
14	16.182	23396.205	4.592	95.721	105.693
15	11.475	15570.883	1.821	70.939	70.114
16	6.914	41761.008	1.763	169.157	130.554
17	9.257	34802.91	1.146	75.946	108.143

3 Results

The regression analysis was conducted to assess how energy efficiency, control system costs, and user satisfaction influence the effectiveness of eco marketing in construction projects. The findings are outlined in Table 2.

It provides greater explanatory power ($R^2 = 0.983$). The regression analysis results were computed using the ordinary least squares (OLS) regression method, employing a sample size of 100 observations. The results in Table 2 show each independent variable's coefficient values and p-value values.

Table 2. Linear regression results

eco_marketing_ effe~s	Coef.	St. Err.	t-value	p-value	[95% Conf	Interval]	Sig
energy_efficiency	.376	.075	5.00	0	.227	.525	***
control_system_cost	.002	0	70.23	0	.002	.002	***
user_satisfaction	3.662	.268	13.65	0	3.129	4.194	***
Constant	27.369	1.396	19.60	0	24.598	30.141	***
Mean dependent var		105.438	SD dependent var		22.810		
R-squared		0.983	Number of obs			100	
F-test		1799.148		Prob > F		0.000	
Akaike crit. (AIC)		511.528	Bayesian crit. (BIC)		521.948		
		*** p<.01, ** p<.05, * p<.1					

The first hypothesis examined the relationship between energy efficiency and eco-marketing effectiveness. For energy efficiency, the results ($\beta = 0.376$, $\rho < 0.01$) showed a significant positive relationship between energy efficiency and eco-marketing effectiveness. Thus, the hypothesis is considered supported.

Next, the second hypothesis proposed a direct relationship between control system cost and the effectiveness of the eco-marketing strategy. The path between them was statistically significant, with the result depicting ($\beta = 0.002$, $\rho < 0.01$), so the hypothesis is confirmed.

The third and fourth hypotheses suggested a strong positive relationship between user satisfaction and eco-marketing effectiveness (H3). The findings confirm the association between user satisfaction and eco-marketing effectiveness ($\beta = 3.662$, $\rho < 0.01$). Additionally, the relationship between the constant term and eco-marketing effectiveness ($\beta = 27.369$, $\rho < 0.01$) was also found to be statistically significant.

The relationships between energy efficiency, control system cost, and user satisfaction (H1, H2, H3) mediated through eco-marketing effectiveness were proposed in prior studies, industry reports, and theoretical models. They were also confirmed because of the results ($\beta = 0.376$, $\rho < 0.01$), ($\beta = 0.002$, $\rho < 0.01$), ($\beta = 3.662$, $\rho < 0.01$).

The last hypothesis was also accepted, which claimed that user satisfaction moderates the relationship between control system cost and eco-marketing effectiveness ($\beta = 3.662$, $\rho < 0.01$). Table 3 shows that each unit increase in user satisfaction strengthens the control system cost and eco-marketing effectiveness relationship.

Table 3. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
project id	100	50.5	29.011	1	100
energy efficiency	100	12.038	4.236	5.301	19.849
control system cost	100	31089.825	11016.404	10185.281	49393.648
user satisfaction	100	2.757	1.178	1.052	4.987
compliance rating	100	75.095	14.751	50.55	99.383
eco marketing effects	100	105.438	22.81	59.63	145.228

Table 3 unveils the results of statistical characterization pertaining to the variables used in the analysis. Notably, there exists a significant disparity between the maximum and minimum values of control system cost, suggesting substantial variation among construction projects. The mean value of the control system cost stands at 31,089.825, accompanied by a standard deviation of 11,016.404. This signifies that certain projects exhibit higher values of control system cost, emphasizing the implementation of advanced technological solutions throughout their development. The statistical measures pertaining to user satisfaction reveal a more equitable distribution of satisfaction levels among the analyzed projects.

In AHP evaluation, descriptive statistics can assess the potential variability in cost factors and user satisfaction impacts of control systems from a quantitative perspective without being influenced by subjective biases. This helps to avoid possible inconsistencies and misjudgments in eco-marketing strategy decision-making, thereby increasing the effectiveness of factor prioritization, which in turn strengthens the contribution of technical, economic, environmental, and social criteria to sustainable construction adoption.

The AHP technique was used to rank the factors affecting the implementation of control systems in eco-friendly building projects (Table 4). The process involved organizing factors, comparing them in pairs, ensuring consistency, and calculating priorities. To start off, the factors were grouped into four categories: Technical, Economic, Environmental, and Social. Subcategories within each category were determined with input from experts. These experts then evaluated the criteria and sub-criteria through pairwise comparisons to create a comparison matrix.

Table 4. AHP pairwise comparison and priority calculation

Criteria	Sub-Criteria	Pairwise Comparison Matrix	Priority
Technical	Sensor Accuracy	1, 3, 5, 2	0.352
	Communication Protocols	1/3, 1, 2, 1/2	0.176
Data Processing Capabilities		1/5, 1/2, 1, 1/3	0.175
Economic	Initial Cost	1, 2, 3, 1	0.082
	Maintenance Cost	1/2, 1, 2, 1/3	0.077
	Return on Investment	1/3, 1/2, 1, 1/2	0.088
Environmental	Energy Savings	1, 2, 1.5, 0.667	0.115
	Resource Optimization	1/5, 1/2, 1, 1/3	0.095
	Emission Reduction	1/3, 1, 2, 1/2	0.091
Social	User Satisfaction	1, 2, 3, 1	0.103
Compliance with Regulations		1/5, 1/2, 1, 1/3	0.087
	Consumer Awareness	1/3, 1, 2, 1/2	0.110

After assessing the reliability of the comparisons, it was found that the consistency index (CI) and consistency ratio (CR) fell within limits (CR = 0.08). Moving on to prioritize factors, technical criteria emerged as the aspect influencing the implementation of intelligent control systems, in green construction, followed by economic, environmental, and social criteria. Ultimately, incorporating control systems has proven to boost eco marketing effectiveness in construction with energy efficiency, system cost, and user satisfaction playing pivotal roles. The AHP analysis further emphasizes the significance of aspects in adopting these systems.

4 Discussion

The study's results offer insights into how smart control systems can be integrated into eco marketing strategies for green construction. The research addresses the goals outlined in the Introduction and contributes to enhancing our knowledge of how technology can support practices in the construction sector.

The regression analysis indicates that energy efficiency, the cost of control systems, and user satisfaction play roles in affecting the effectiveness of eco marketing. These findings are consistent with existing literature that highlights the significance of energy technologies and user involvement in promoting construction practices. However, this study goes a step further by quantifying the impact of these factors within the realm of control systems, providing a more detailed understanding of their contributions.

With a high R-squared value (0.983), it becomes evident that the model explains a substantial portion of the variation in eco marketing effectiveness. This result underscores how intelligent control systems have the potential to revolutionize eco marketing strategies by enhancing transparency, efficiency, and consumer confidence. The significant coefficients, for energy efficiency (0.376), control system cost (0.002), and user satisfaction (3.662), underscore the benefits associated with incorporating advanced technologies into green construction practices. Additionally, through Analytical Hierarchy Process (AHP) analysis, a clearer picture emerges regarding which factors hold importance in driving adoption rates for control systems.

The key aspects to consider, especially when it comes to sensor precision, communication standards, and data processing capacities, were identified as crucial, making up 64.3% of the importance. This underscores the need, for dependable solutions to support the effective deployment of smart control systems. Additionally, economic, environmental and social factors also hold weight with priorities of 24.7%, 15.3% and 29.0% respectively. These discoveries align with the approach for sustainable progress considering not just technical and economic elements but also environmental consequences and societal acceptance.

The consistency ratio (CR) of 0.08 in the AHP assessment signifies the reliability of expert's comparisons. This reinforces trust in the prioritization process. Underscores the significance of considerations in integrating smart control systems. The prioritization of sensor accuracy, communication protocols and data processing capabilities as sub criteria emphasizes the need for accurate and efficient systems to optimize eco-friendly construction projects.

These findings have implications for marketing strategies. Firstly, focusing on energy efficiency and user satisfaction in efforts can boost consumer involvement and confidence. Highlighting the advantages of control systems, like lower operational expenses and improved return on investment, can attract a wider audience that includes financially conscious stakeholders.

Moreover, lower emissions and efficient resource utilization can attract consumers who are environmentally conscious. The research also points to areas for exploration. Studying the lasting effects of control systems on building performance and user satisfaction could yield insights into their sustainability advantages. Delving into the combination of cutting-edge technologies like AI and IoT with control systems could boost their capabilities and effectiveness further. In summary, this study showcases how smart control systems seem promising in terms of improving eco-marketing strategies for sustainable construction. By measuring the influence of factors and prioritizing criteria, the research offers a solid foundation for crafting and executing eco-conscious marketing plans.

5 Conclusion

This research offers evidence supporting the use of control systems in eco-friendly marketing approaches for green buildings. The key takeaways from the findings and subsequent discussions are as follows; The analysis showed that energy efficiency, control system expenses, and user satisfaction play a role in the effectiveness of eco marketing. These results highlight the importance of incorporating advanced technology solutions that improve energy efficiency and user satisfaction while remaining cost-efficient. The assessment using AHP emphasized the importance of aspects, sensor precision, communication protocols, and data processing capabilities in adopting smart control systems. This prioritization underscores the need for efficient systems to optimize building projects. The study stresses the necessity for a strategy that considers environmental social criteria along with technical factors. This approach aligns with development goals that require balancing aspects to ensure long-term sustainability. The results indicate that highlighting the environmental benefits of smart control systems can significantly enhance eco marketing strategies, leading to greater consumer engagement, trust, and investment in sustainable construction solutions.

The significance of this research lies in its contribution to understanding how intelligent control systems can be effectively incorporated into eco marketing strategies. The research outlines an approach to developing and implementing marketing strategies in the construction industry by evaluating key factors and prioritizing critical criteria. With a R value of 0.983 the models strong explanatory power highlights the significant impact of these factors on eco marketing effectiveness offering valuable insights for industry professionals and policymakers.

In summary this study underscores the potential of control systems to boost eco marketing effectiveness, in green construction projects. The expressed results lay a groundwork, for upcoming studies and real-world uses, aiding the progress of eco-friendly building methods and environmentally conscious marketing approaches.

Future studies could delve into areas based on these findings. Exploring how intelligent control systems influence building performance, energy efficiency, and user satisfaction in the term can provide insights into their sustainability benefits. Additionally, investigating the integration of emerging technologies like intelligence, machine learning, and the Internet of Things with control systems could enhance their capabilities further. Examining regional contexts may offer a more comprehensive understanding of how intelligent control systems are adopted and their impact in diverse settings. Analyzing the cost-effectiveness of implementing control systems across types of construction projects can help identify optimal solutions.

References

1. Chen, Z., & He, Y. Artificial intelligence and environmental protection of buildings. Problemy Ekorozwoju. **18,** 2 254–262 (2023)
2. Tuz, A., & Sertyeşilışık, B. The preliminary step towards conceptual model for the artificial intelligence-neuro-green marketing in the architectural engineering and construction industry. J. Tech.Archi. Design Plan. **1,** 2 140–150 (2024)
3. Y. Sheikhnejad, A. Baniassadi, G. Happle, Can buildings be more intelligent than users? The role of intelligent supervision concepts integrated into building predictive control. Energ. Buil. **224,** 110238 (2020). https://doi.org/10.1016/j.enbuild.2020.110238
4. M. Um-e-Habiba, M. S. Khan, S. Rehman, A review on enhancing energy efficiency and adaptability through system integration for smart buildings. J. Buil. Engi. **50,** 104167 (2024). https://doi.org/10.1016/j.jobe.2022.104167
5. K. Rakhmatovich, Fundamentals of Targeted Integrative Program Development for Rural Labor Market Growth in Surplus Regions. Int. J. Eco. Fin. Iss. **14,** 4 239-244 (2024)
6. S. Kholmuminov, B. Tursunov, M. Saidova, L. Abduhalilova, N. Sadriddinova, Improving the analysis of business processes in digital era. (Proceedings of the 5th International Conference on Future Networks and Distributed Systems 2021)
7. E. Saber, M. El Mankibi, P. Michel, Review of intelligent control systems for natural ventilation as passive cooling strategy for UK buildings and similar climatic conditions. Energies. **14,** 4 1045 (2021)
8. S. Goyal, Advanced controls for intelligent buildings. Springer. (2021)
9. H. Zhuang, H. Li, Y. Li, Sustainable smart city building construction methods. Sustainability. **12,** 20 8601 (2020). https://doi.org/10.3390/su12124947
10. S. Mischos, D. Tzovaras, Intelligent energy management systems: A review. Arti. Intell. Rev. **55,** 1301–1341 (2022). https://doi.org/10.1007/s10462-023-10441-3

11. D. Goncalves, J. Henriques, C. H. Antunes, C. H. One step forward toward smart city utopia: Smart building energy management based on adaptive surrogate modelling. Ener. Buil. **224,** 110292 (2020). https://doi.org/10.1016/j.enbuild.2020.110146
12. M. Patil, P. A. Patil, comprehensive review on emerging trends in smart green building technologies and sustainable materials. Materials Today: Proceedings. **56,** 2205–2211. (2022). https://doi.org/10.1016/j.matpr.2022.04.866
13. S. Kholmuminov, S. Kholmuminov, R. E. Wright, Resource dependence theory analysis of higher education institutions in Uzbekistan. Hig. Edu. **77,** 1 (2019)
14. A. Dounis, Machine intelligence in smart buildings. Energies. **16,** 1 22. (2022). https://doi.org/10.3390/en16010022
15. Y. Wang, N. Li, Indoor environmental wellness index (IEW-Index): Towards intelligent building systems automation and optimization. *Building and Environment* **247,** 111039 (2023). https://doi.org/10.1016/j.buildenv.2023.111039
16. J. Riahi, S. Kamel, Intelligent control of the microclimate of an agricultural greenhouse powered by a supporting PV system. Appl. Sci. **10,** 4 1350 (2020). https://doi.org/10.3390/app10041350