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A SYSTEM DYNAMICS MODEL FOR MANAGING THE STRATEGIC PERFORMANCE OF CONSTRUCTION ENTERPRISES IN A GREEN ECONOMY

Shakhlo Bakhtiyor kizi G'ulomova
PhD Student, Tashkent University of Architecture and Civil Engineering
Tashkent, Uzbekistan | E-mail: shaxlochka0599@gmail.com
ORCID: 0009-0008-3226-2108

Abstract. This article substantiates the use of system dynamics methodology for managing the strategic performance of construction enterprises during the transition to a green economy. The study adopts a conceptual and scenario-based design and applies content analysis, comparative analysis, causal loop modelling, and stock-and-flow modelling principles. The proposed model integrates external institutional and market factors, internal resources and dynamic capabilities, green and digital management mechanisms, construction processes, and economic-environmental outcomes within a unified system. Reinforcing and balancing feedback loops among green investment, building information modelling (BIM), human capital, resource efficiency, rework, and financial capacity are identified. The conceptual analysis indicates that system dynamics can be used to compare the short- and long-term consequences of strategic decisions, identify time delays, and virtually test alternative scenarios. The model is proposed as a methodological foundation for developing green transformation strategies in construction enterprises in Uzbekistan.

Keywords: system dynamics, strategic performance, green economy, construction enterprise, feedback loop, time delay, BIM, green investment, resource efficiency.

INTRODUCTION

The construction industry plays a crucial role in economic growth, the expansion of industrial and social infrastructure, and employment. At the same time, the buildings and construction sector consumes substantial amounts of energy and materials. The 2025–2026 report by UNEP and GlobalABC states that the sector is associated with nearly 37% of global carbon dioxide emissions and almost half of global material extraction [1]. Therefore, assessing the strategic performance of construction enterprises solely through profit and the volume of completed work overlooks resource intensity, waste generation, and long-term environmental risks.

The expansion of construction activity in Uzbekistan makes this issue relevant at the national level. According to preliminary data from the National Statistics Committee, construction work worth UZS 313.8 trillion was performed in 2025, representing growth of 14.2% compared with 2024 [2]. The increase in activity creates new market opportunities for enterprises, but it also intensifies the managerial burden associated with project portfolio complexity, material supply, information flows, financing, and environmental obligations.

Resolution No. PQ-436 of the President of the Republic of Uzbekistan, dated 2 December 2022, approved the national programme for transition to a green economy by 2030. It sets targets to reduce greenhouse gas intensity by 35% relative to the 2010 level, increase industrial energy efficiency by at least 20%, and expand resource efficiency [3]. For construction enterprises, these targets require energy-efficient technologies, BIM, green procurement, waste reduction, and environmental monitoring to be treated not as isolated technical measures but as integral components of strategic management.

The Balanced Scorecard (BSC) converts strategy into measures across financial, customer, internal process, and learning and growth perspectives [4]. However, a static strategy map does not adequately represent when an effect will occur, how factors reinforce or constrain one another, or how stocks accumulate over time. Yildiz, Dikmen, and Birgonul integrated a BSC-based strategy map with system dynamics and demonstrated that the likely outcomes of strategic options can be simulated under changing internal processes and external conditions [5]. They also noted limitations related to model generalisability, practical usability, and validation.

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LITERATURE REVIEW

System dynamics (SD) explains the behaviour of complex systems through causal relationships, feedback loops, stocks, flows, and time delays [6, 7]. In construction processes, project changes, incomplete information, work pressure, supply disruptions, and rework are interdependent; therefore, evaluating individual risks in isolation may understate the behaviour of the overall system. Love et al. examined the mutually reinforcing effects of project changes and rework [8]; Han, Love, and Peña-Mora modelled the mechanism through which design errors and schedule pressure propagate delays [9]; and Leon et al. demonstrated the possibility of integrating cost, time, quality, safety, environmental performance, and stakeholder satisfaction within a single model [10].

Research on green construction and digital transformation also confirms the need for a dynamic approach. Zoghi and Kim showed that the costs and benefits of BIM-based construction waste management emerge differently over the project life cycle [11]. Zhang et al. found that green innovation mediates the effect of BIM on sustainability performance [12]. However, many models in these fields focus on the project level, while feedback relationships among corporate financial capacity, human capital, environmental performance, and reinvestment are less frequently integrated.

Accordingly, this study aims to develop a conceptual system dynamics model that represents the feedback relationships and time delays among external institutional and market factors, internal resources and dynamic capabilities, green and digital management mechanisms, construction processes, and economic-environmental outcomes in order to manage the strategic performance of construction enterprises in Uzbekistan under green economy conditions. The scientific contribution lies not in the method itself, but in integrating these factors into a unified strategic structure adapted to the context of Uzbek construction enterprises.

RESEARCH METHODOLOGY

The study employs a conceptual and scenario-based design. Because complete dynamic time-series data and a calibrated simulation for an actual enterprise are not available, hypothetical numerical values are not presented as empirical findings. The methodology combines a systems approach, content analysis of scientific literature, comparative analysis, causal loop diagrams (CLDs), stock-and-flow diagrams (SFDs), and scenario analysis.

The literature was selected across the theoretical foundations of system dynamics, strategic performance in construction, project errors and delays, material supply, BIM, green innovation, and waste management. Four criteria were used to include variables in the model: evidence of a causal influence on construction outcomes; the possibility of modification through managerial decisions; accumulation or delay over time; and relevance to economic and environmental results.

The model boundary covers corporate- and project-level management processes in a large construction enterprise. The system consists of five blocks: external institutional and market factors; internal resources and dynamic capabilities; green and digital management mechanisms; construction production processes; and economic, environmental, and strategic outcomes. The broader intersectoral effects of the macroeconomy and all technical processes during the operational phase of buildings were excluded from the model boundary (table 1).

Table 1. System dynamics model blocks and key variables

Model block	Key variables	Function in the system
External environment	environmental regulations; energy and material prices; market demand; financing; competition	exogenous pressures and opportunities
Internal resources	financial reserves; human capital; BIM and digital infrastructure; innovation capacity	capability to implement strategy
Green and digital mechanisms	energy-efficient technologies; BIM; resource audits; green procurement; waste monitoring	managerial interventions that transform processes
Construction process	backlog; productivity; errors; rework; schedule; material, energy, and water consumption	operational stocks and flows
Strategic outcomes	cost; profitability; quality; customer satisfaction; environmental performance; reputation; new orders	final outcomes and sources of reinvestment

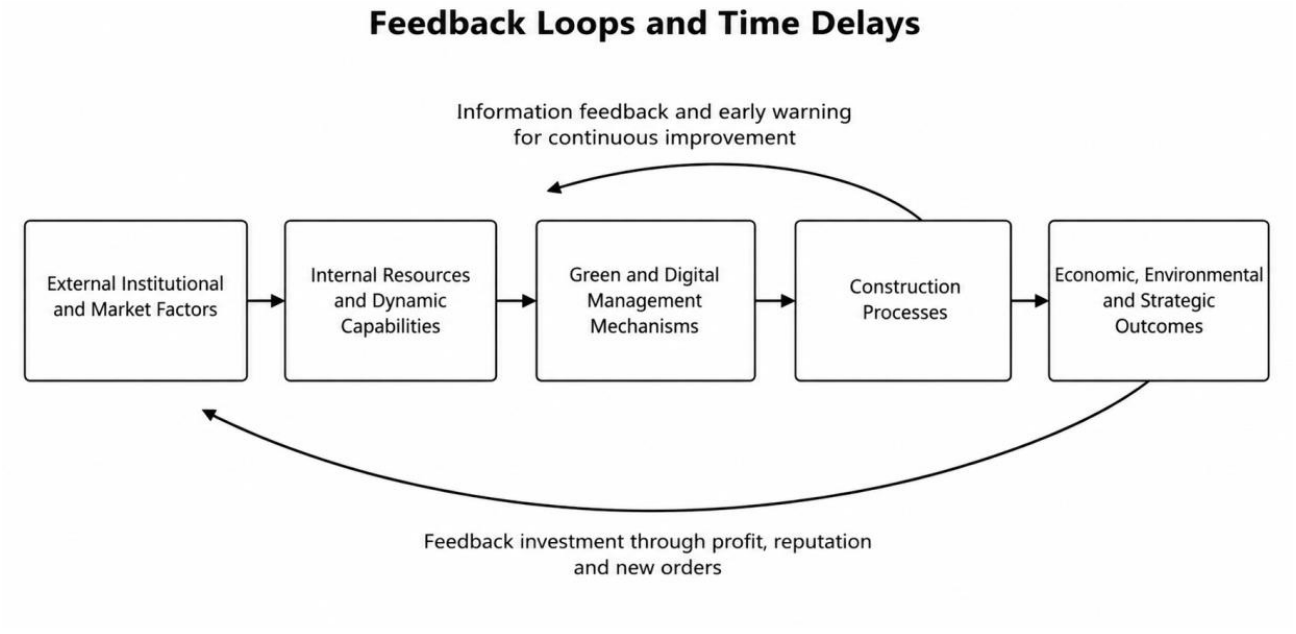
Source: Author's development.

In a CLD, a relationship is defined as positive when an increase in one variable changes another variable in the same direction, and negative when it changes it in the opposite direction. A reinforcing loop (R) amplifies change in the system, whereas a balancing loop (B) constrains or stabilises it. The selected stocks are backlog, financial resources, green technological capability, BIM capability, skilled human capital, construction waste, and strategic reputation. Their general dynamics are expressed as follows: Stock(t) = Stock(t−1) + inflow − outflow.

For example, the backlog stock increases through new contracts and rework and decreases through the flow of completed work. Green capability accumulates as investments are absorbed and declines through technological obsolescence. The delay between investment and results, the delay between employee training and productivity growth, and the delay between environmental reputation and new orders are the model's principal time parameters.

Scenario analysis covers four alternative conditions: a baseline scenario in which existing practices are maintained; a green transformation scenario in which energy efficiency and waste reduction are intensified; a digital-green integration scenario in which green measures are combined with BIM, ERP, and employee training; and an adverse external environment scenario characterised by rising material and energy prices and tighter financing and supply constraints.

For subsequent empirical validation, the model should undergo structural verification, dimensional consistency testing, extreme-condition testing, parameter sensitivity analysis, comparison with historical behaviour, and face validation involving experts [18–21]. These procedures are intended to assess the model not as an absolute representation of reality, but as a decision-support tool with sufficient reliability for its specified purpose.



Source: Author's development based on [5–7, 11–16].

Figure 1. Conceptual system dynamics model for managing the strategic performance of a construction enterprise

The figure shows that strategic outcomes are not an endpoint: profit, reputation, and new orders refinance internal capabilities, while information generated by construction processes updates management mechanisms. The model therefore represents a closed feedback system rather than a linear sequence.

ANALYSIS AND RESULTS

Conceptual analysis indicates that the strategic performance of a construction enterprise is not a single financial measure, but an outcome that evolves over time through interconnected capabilities and processes. External environmental requirements and market pressure reshape investment priorities; investments build human, digital, and green capabilities; these capabilities affect errors, productivity, resource consumption, and waste; and process outcomes determine future investment capacity through profit, customer satisfaction, and reputation.

In the R1 green investment loop, improvements in energy and material efficiency reduce cost and strengthen profit and investment capacity. However, this loop does not operate immediately. During the period required to purchase equipment, assimilate technology, and reorganise work processes, the B1 financial constraint loop dominates by reducing free cash flow. Consequently, a short-term assessment may understate the long-term value of green investment.

The R2 BIM loop operates through project information accuracy, errors, and rework. As BIM capability improves, the enterprise becomes better able to detect clashes before construction and plan material requirements accurately. This reduces rework and time losses. Nevertheless, implementing BIM solely as a software product is insufficient: if employee skills, data standards, and interdepartmental integration are inadequate, technical, information, and organisational risks may form mutually reinforcing adverse loops [17].

In the R3 human capital loop, training and experience improve labour productivity and quality. Better quality strengthens customer satisfaction and repeat orders, which generate additional resources for skills development. The delay between training and actual productivity improvement is important: training may reduce productive time in the short term, but it lowers errors and rework over the longer term.

The R5 delay-cost spiral is the principal adverse mechanism in the model. Project complexity, design errors, or disruptions in material delivery cause delays. When work pressure is increased to recover the schedule, coordination may deteriorate and new errors and rework may emerge. Han et al. showed that schedule pressure can spread the effects of design errors to other activities [9]; Wang and Yuan found that the combined impact of risks on the schedule may exceed the sum of risks assessed separately [13]. A dynamic model of material supply also indicates that information gaps among procurement, logistics, and construction reinforce cost and schedule problems [14].

The B2 waste reduction loop treats waste not as a residual generated at the end of construction, but as a management outcome that begins at the design stage. Accurate material quantity estimation, design suited to modularisation and prefabrication, sorting, and reuse reduce the volume sent to landfill. The models developed by Ding et al. demonstrate that source reduction and integration of the design and construction stages can substantially influence environmental outcomes [15, 16]. Zoghi and Kim showed that the initial costs and life-cycle benefits of BIM-based waste management arise at different points in time (table 2)[11].

Table 2. Main feedback loops and their strategic significance

Loop	Main causal chain	Strategic significance
R1	green investment → resource efficiency → lower costs → profit → reinvestment	long-term self-reinforcing growth
R2	BIM → information accuracy → fewer errors and less rework → time and cost savings	conversion of digital capability into operational results
R3	skills → productivity and quality → customer satisfaction → orders → training capacity	strategic returns on human capital
R4	environmental performance → reputation → green orders → revenue → environmental investment	link between market and environmental outcomes
B1	investment → capital expenditure → reduced free cash flow → investment constraint	short-term financial pressure
R5	delay → work pressure → errors and rework → costs → resource shortage → delay	adverse spiral and risk to project stability
B2	waste → management cost → waste-reduction investment → reuse and recycling	balancing the environmental burden

Source: Author's development.

The loops do not operate independently. For example, reduced rework through R2 strengthens the cost savings in R1, whereas the cash-flow constraint in B1 may simultaneously slow investment in both BIM and green technologies. Accordingly, the enterprise should manage the balance among loops rather than maximise a single indicator (table 3).

Table 3. Expected directional changes under the strategic scenarios

Scenario	Initial financial burden	Rework and delay	Resource intensity	Long-term strategic outcome
Baseline	low	improves slowly	nearly stable	limited competitive advantage
Green transformation	moderate–high	partially declines	declines	greater environmental and financial resilience
Digital-green integration	high	largest reduction expected	declines significantly	highest long-term strategic potential
Adverse external environment	high pressure	risk of increase	sensitive to prices and supply	depends on digital capability and reserves

Note: The results in the table are not empirical forecasts; they are directional assessments derived from the causal structure of the model. Source: Author's development.

The baseline scenario requires no major organisational change in the short term, but limits enterprise adaptability as environmental requirements, energy prices, and digital competition intensify. Green transformation reduces resource and waste intensity; however, if information integration remains insufficient, measuring results across projects becomes difficult.

The digital-green integration scenario initially requires the greatest financial and organisational resources. According to the model structure, when BIM, environmental monitoring, ERP, and employee capabilities are developed together, several loops associated with errors, rework, material loss, and delay shift simultaneously in a favourable direction. Under an adverse external environment, previously developed digital capability, financial reserves, and a diversified supply chain become the primary factors strengthening enterprise resilience.

The proposed model shares its methodological foundation with the dynamic strategy map developed by Yildiz, Dikmen, and Birgonul: strategy is treated as a dynamic system linking external conditions, internal resources, and performance measures [5]. The distinguishing feature of the present study is that it centrally connects green investment, BIM, resource efficiency, and waste with corporate financial capacity and reinvestment loops. Sustainability is therefore treated not as a separate BSC perspective but as a mechanism interacting with all other perspectives [23].

The findings extend Love et al.'s conclusions regarding change and rework [8], Han et al.'s model of design errors and schedule pressure [9], and Leon et al.'s approach to integrated assessment of multidimensional performance measures [10]. Whereas these studies demonstrate the non-linearity of project performance, the proposed model also accounts for the feedback of project outcomes into corporate investment capacity.

The tension between short-term cost and long-term benefit demonstrates the main advantage of system dynamics for strategic decision-making. The initial cost of green technology or BIM is recorded immediately, whereas resource savings, error reduction, and new orders generated through reputation emerge with a delay. A single-period assessment may understate these benefits. An SD model represents delays and accumulation, allowing a strategy to be tested virtually before implementation.

However, the practical value of the model depends on data quality and user participation. Yildiz et al. identified generalisability, usability, and validation as major limitations [5]. Group model building helps integrate the knowledge of executives, project managers, engineers, finance specialists, procurement professionals, environmental specialists, and BIM coordinators [20, 21]. Even so, the subjectivity of expert judgement, the model boundary, and simplifying assumptions may affect results. Therefore, the conceptual model should not be interpreted as an absolute forecast until it has been calibrated with enterprise-specific data.

Adaptation to the context of Uzbekistan should account for differences in enterprises' technological readiness, financial capacity, energy and material markets, quality of environmental reporting, and government incentives. In an emerging economy, local organisational characteristics may strongly affect strategic outcomes; earlier research applying system dynamics to construction organisation performance likewise showed that strategic options must be selected in accordance with local conditions [22].

Construction enterprises are advised to introduce a dynamic strategy map that monitors not only financial indicators but also the share of rework, material and energy intensity, waste volume, BIM utilisation, employee skills, customer satisfaction, and environmental reputation. The map should be updated at least annually, and alternative strategies should be evaluated through scenarios.

BIM, ERP, project schedules, material accounting, and environmental monitoring data should be integrated into a unified management environment. This would enable automatic updating of model parameters, reduce the risk of data manipulation, and facilitate early detection of the delay-cost spiral. Early-warning thresholds should be defined for the rework rate, material delivery delays, energy consumption, planned-versus-actual cost variance, and clashes detected through BIM.

Green investments should be assessed on the basis of life-cycle value rather than as one-year costs. Decision-making should consider energy and material savings, service life, waste transport and disposal costs, revenue from reuse, environmental risk, and reputational effects. Enterprises may first pilot the model in one large project or organisational unit with complete data and then expand it to the corporate level.

At the public administration level, it is necessary to develop unified reporting criteria for energy, materials, water, waste, and carbon indicators; strengthen BIM-based environmental monitoring; expand green public procurement; and encourage the use of recycled construction materials. Green financing mechanisms should consider not only project certification but also the enterprise's actual resource efficiency and dynamic monitoring capability.

In the subsequent empirical stage, the model should be calibrated using at least five years of financial, project, energy, and environmental data from large construction enterprises, simulated in Vensim or Stella Architect, and tested against historical data, extreme conditions, and sensitivity analysis.

CONCLUSION AND SUGGESTIONS

This study proposes a conceptual system dynamics model for managing the strategic performance of construction enterprises in Uzbekistan under green economy conditions. The model integrates external institutional and market factors, internal resources and dynamic capabilities, green and digital management mechanisms, construction processes, and economic-environmental outcomes within a unified feedback system.

Conceptual analysis indicates that strategic performance is not limited to the volume of completed work or profit. It emerges through dynamic relationships among BIM data quality, rework, material and energy intensity, employee skills, supply stability, waste, and environmental reputation. Green and digital investments may create financial pressure initially, but can subsequently reinforce profit and further investment through resource savings and reduced errors.

The scientific contribution of the article lies not in system dynamics itself, but in integrating economic, environmental, digital, and organisational indicators into a unified strategic model adapted to construction enterprises in Uzbekistan, and in proposing a mechanism for evaluating time delays and alternative scenarios.

The main limitation of the study is the absence of quantitative calibration and simulation using real enterprise data. The results should therefore be interpreted not as absolute forecasts, but as a theoretical and methodological foundation for empirical research and management model development. Future studies should test the model using enterprise-level panel and project data, quantify scenario effects, and pilot the integration of BIM, ERP, and environmental monitoring.

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