

Smart Technologies as Tools for Developing Sustainable Leadership Competencies in the Education System: A Conceptual Model and Directions for Empirical Validation

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Abstract: Global environmental and socio-economic challenges have intensified the need to cultivate sustainable leadership competencies through educational systems. As education undergoes rapid digital transformation, smart technologies—such as artificial intelligence, adaptive platforms, data analytics, and immersive learning environments—are increasingly integrated into teaching and learning processes. However, their role in fostering sustainable leadership competencies remains insufficiently theorized. This study develops a conceptual model in which smart technology integration contributes to the development of sustainable leadership competencies through a sequential mediation pathway: systems thinking, environmental responsibility, and strategic decision-making. In addition, institutional orientation toward sustainable development is proposed as a moderating factor that strengthens the relationship between smart technology integration and systems thinking. The article advances the literature by bridging research on digital transformation, sustainability, and leadership development within a unified theoretical framework. It also provides a foundation for future empirical validation using structural equation modeling (SEM)/PLS-SEM and offers practical guidance for the design of sustainability-oriented educational programs.

Keywords: Smart technologies; Sustainable leadership; Digital transformation of education; Systems thinking; Environmental responsibility; Strategic decision-making; Structural equation modeling (SEM)

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1. Introduction

Contemporary society faces interconnected global challenges, including climate change, resource depletion, biodiversity loss, social inequality, and rapid technological transformation. These systemic pressures require not only technological solutions but also shifts in leadership paradigms toward long-term value creation, environmental responsibility, and intergenerational justice^[1]. In this context, sustainable leadership becomes increasingly critical.

The development of sustainable leadership competencies begins within educational systems^[1], where universities shape strategic thinking, ethical reflection, and an understanding of the interconnections among economic, social, and environmental processes^[2]. However, traditional education—largely centered on knowledge transmission and standardized assessment—often falls short in fostering complex leadership competencies.

At the same time, education is undergoing rapid digital transformation. The integration of smart technologies—such as artificial intelligence, adaptive platforms, data analytics, and simulation-based environments—is reshaping learning processes^[3,4]. While research has primarily examined digitalization in terms of efficiency and academic performance^[5], considerably less attention has been paid to how smart technologies may contribute to the development of sustainable leadership^[6].

A key research gap lies in the absence of a comprehensive theoretical model explaining the mechanisms through which smart technology integration influences sustainable leadership competencies, particularly through cognitive and value-based processes and within specific institutional contexts^[4,7].

This study develops a theoretically grounded conceptual model in which the integration of smart technologies contributes to sustainable leadership development through a sequential pathway—systems thinking → environmental responsibility → strategic decision-making—while considering institutional orientation toward sustainability as a moderating factor, and formulates hypotheses for empirical testing using structural equation modeling (SEM).

2. Theoretical foundations

2.1. Sustainable leadership as a response to contemporary systemic challenges

The concept of sustainable leadership has emerged at the intersection of sustainable development theory, strategic management, and organizational behavior. Unlike traditional leadership models that emphasize short-term efficiency and competitiveness, sustainable leadership entails a long-term orientation, consideration of environmental and social consequences, and accountability to diverse stakeholder groups^[8].

Sustainable leadership refers to a leader's ability to formulate strategies that balance economic performance, social equity, and environmental sustainability^[9]. Core competencies include systems thinking, strategic foresight, ethical reflection, the capacity to manage complexity, and decision-making under uncertainty^[10]. Contemporary research highlights that sustainable leadership requires cognitive and value-based orientations enabling leaders to understand systemic interconnections and integrate sustainability principles into managerial practice^[11].

2.2. Digital transformation of education and the potential of smart technologies

The digital transformation of education represents a structural shift in learning processes driven by information and communication technologies^[3]. Smart technologies—including artificial intelligence, adaptive platforms, data analytics, and immersive environments—enable personalized learning, engagement with real socio-economic and environmental data, and the modeling of complex decision-making scenarios^[2,12].

Unlike traditional linear instruction, these technologies create interactive environments in which learners actively engage with simulations, analyze alternative scenarios, and evaluate consequences of strategic choices^[4]. However, existing research predominantly examines digitalization in terms of efficiency and academic performance, leaving its role in fostering sustainable leadership competencies insufficiently conceptualized.

2.3. Systems thinking as the cognitive foundation of sustainable leadership

Systems thinking is a core cognitive competency of sustainable leadership. It refers to the ability to perceive phenomena as interconnected elements of an integrated system, accounting for nonlinear effects, feedback loops, and long-term consequences^[13].

In the context of environmental challenges, systems thinking supports understanding the interactions among economic, social, and ecological processes^[14]. Without this competency, leadership decisions may remain fragmented and produce unintended consequences^[15].

Smart technologies foster systems thinking through data visualization, scenario modeling, and simulation of complex processes^[7]. Digital tools enable learners to observe system dynamics, analyze strategic alternatives, and experiment with different courses of action^[16].

2.4. Environmental responsibility and strategic decision-making

Sustainable leadership also requires a value-based dimension—environmental responsibility—reflecting an individual's orientation toward resource preservation, environmental protection, and sustainable development principles^[11,12].

While systems thinking facilitates awareness of interdependencies, the transition from understanding to action depends on value-based commitment. Environmental responsibility acts as an intermediate link between systemic awareness and strategic decision-making^[16].

Strategic decision-making involves evaluating long-term risks, comparing alternative scenarios, and balancing stakeholder interests. Smart technologies can reinforce this process through simulations, case-based learning, and engagement with real-world data.

3. Development of the conceptual model and hypothesis formulation

3.1. Integration of smart technologies and the development of systems thinking

The integration of smart technologies transforms learners' cognitive processes by enabling the visualization of complex interconnections, the modeling of alternative scenarios, and the analysis of decision consequences. Simulation and analytical tools facilitate the understanding of nonlinear effects, feedback loops, and systemic risks, thereby strengthening integrative perceptions of sustainability-related challenges.

H1: The integration of smart technologies positively influences the development of learners' systems thinking.

3.2. Systems thinking and environmental responsibility

The development of systems thinking enhances awareness of the interconnections between human activities and ecosystem conditions, thereby reinforcing an internal orientation toward sustainability. Cognitive understanding of systemic complexity facilitates the internalization of sustainability values by linking analytical awareness with moral evaluation of environmental consequences.

H2: Systems thinking positively influences the formation of environmental responsibility.

3.3. Environmental responsibility and strategic decision-making

Environmental responsibility increases the willingness to consider long-term risks and stakeholder interests in strategic analysis. A value-based orientation toward sustainability strengthens the integration of environmental criteria into decision-making processes.

H3: Environmental responsibility positively influences the development of strategic decision-making.

3.4. Strategic decision-making and sustainable leadership competencies

Strategic analysis skills and the consideration of long-term consequences serve as operational mechanisms in the formation of sustainable leadership, ensuring the integration of sustainable development principles into managerial practice.

H4: Strategic decision-making positively influences the development of sustainable leadership competencies.

3.5. Sequential mediated relationship

The integration of smart technologies influences sustainable leadership indirectly—through the development of systems thinking, environmental responsibility, and strategic decision-making.

H5: The integration of smart technologies has an indirect effect on sustainable leadership competencies through a sequential chain of mediators.

3.6. The moderating role of institutional orientation

The effect of technology integration depends on the institutional context. In organizations with a strong orientation toward sustainability, technologies are directed toward the development of sustainability-related competencies; whereas in institutions with a weaker sustainability orientation, their impact may be limited to efficiency-related objectives.

H6: Institutional orientation toward sustainable development strengthens the relationship between the integration of smart technologies and the development of systems thinking.

Figure 1 illustrates the proposed conceptual framework, including the sequential mediation pathway (H1–H5) and the moderating role of institutional orientation toward sustainability (H6).

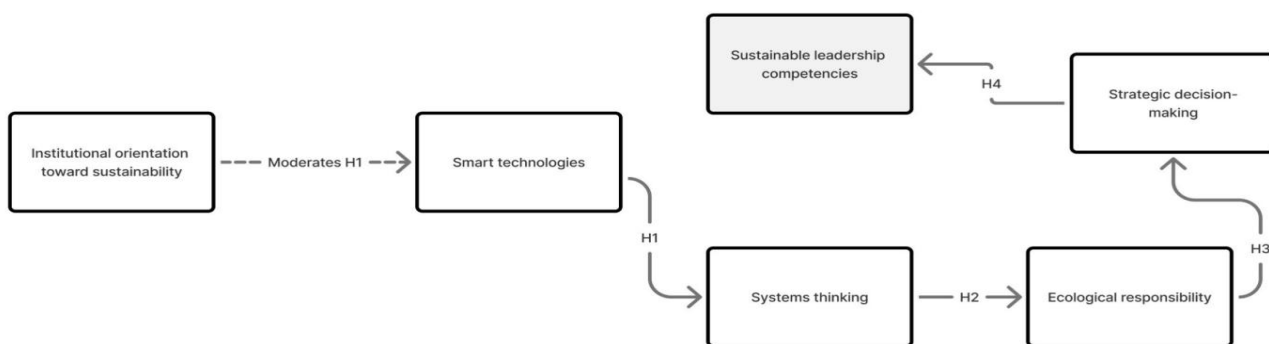


Figure 1. Conceptual model of the development of sustainable leadership competencies

4. Methodological proposals for empirical validation of the model

The proposed conceptual model enables empirical testing using SEM^[17], which enables the simultaneous estimation of direct, indirect, and moderating effects among latent variables^[18].

4.1. Research design

To test the proposed hypotheses, a quantitative survey design may be employed among students in higher

education, master's, MBA, or executive education programs. The sample should include institutions that vary in digital maturity and institutional orientation toward sustainable development to enable testing of the moderating effect of organizational context. For SEM analysis, a minimum sample size of $n \geq 300$ is recommended to ensure adequate statistical power for examining mediated and moderated relationships.

4.2. Operationalization of variables

All variables in the model are intended to be measured as latent constructs using validated scales based on a 5- or 7-point Likert scale. As shown in **Table 1**, each variable is operationalized through established measurement scales, with corresponding dimensions and indicators adapted from prior studies.

Table 1. Operationalization of variables

Construct	Type of variable	Key indicators	Scale type
Integration of Smart Technologies	Independent	Use of AI; simulations; data analytics; adaptive platforms	5–7-point Likert scale
Systems Thinking	Mediator	Analysis of interconnections; consideration of long-term consequences; understanding of nonlinearity	5–7-point Likert scale
Ecological responsibility	Mediator	Sustainability orientation; integration of environmental criteria into decisions	5–7-point Likert scale
Strategic Decision-Making	Sequential mediator	Evaluation of alternative scenarios; long-term planning; risk consideration	5–7-point Likert scale
Sustainable Leadership Competencies	Dependent	Strategic vision; ESG integration; stakeholder orientation	5–7-point Likert scale
Institutional Orientation toward Sustainability	Moderator	ESG strategy; sustainability initiatives; integration of sustainability into curricula	5–7-point Likert scale

4.3. Data analysis

The data analysis is conducted using SEM, following a systematic sequence of steps to ensure the reliability and validity of the measurement model, as well as to test the proposed hypotheses. As shown in **Table 2**, the analysis includes reliability assessment, convergent and discriminant validity evaluation, structural model testing, as well as the examination of indirect and moderating effects.

Table 2. Data analysis plan (SEM)

Analysis stage	Method	Purpose
Reliability Assessment	Cronbach's α , Composite Reliability (CR)	Internal consistency of scales
Convergent Validity	Average Variance Extracted (AVE)	Assessment of explained variance
Discriminant Validity	Heterotrait–Monotrait Ratio (HTMT)	Distinction between constructs
Structural Model Evaluation	Path coefficients (β)	Hypothesis testing
Indirect Effects	Bootstrapping	Mediation testing
Moderation	Interaction term analysis	Testing H6

4.4. Control variables

To enhance the precision of the model, control variables may be included. As shown in **Table 3**, variables such as age, field of study, level of digital competence, and experience in environmental initiatives are considered

because they may influence respondents' perceptions, attitudes, and environmentally responsible behavior.

Table 3. Control variables

Variable	Rationale for Inclusion
Age	May influence cognitive maturity
Field of Study	Differences between STEM and humanities programs
Level of Digital Competence	Influences perception and use of technology
Experience in Environmental Initiatives	May affect ecological responsibility

4.5. Ethical considerations

Since the study involves surveying students, it is necessary to ensure voluntary participation, anonymity, and data confidentiality. If the research is conducted within a university setting, obtaining approval from the relevant institutional ethics committee is recommended.

This methodological design demonstrates that the proposed model is empirically testable and consistent with the standards of quantitative research in the fields of education and organizational behavior.

5. Practical implications

The proposed conceptual model has several practical implications for educational institutions, curriculum developers, and policymakers in the field of education. As shown in **Table 4**, these implications differ across stakeholder groups, but all emphasize the strategic integration of smart technologies to foster sustainability-oriented competencies, leadership development, and value-based decision-making.

Table 4. Practical implications of the conceptual model

Stakeholder	Key implication	Examples of implementation
Educational Institutions	The integration of smart technologies should be strategic and aimed at developing cognitive and value-based competencies, rather than focusing solely on academic performance	Simulations of environmental/managerial dilemmas; work with ESG data; interdisciplinary digital projects
Curriculum Developers	Technologies should be accompanied by value-oriented and strategic content; the sequential development of competencies is essential	Digital modules on sustainable development; project-based learning using real cases; strategic decision-making simulations
Educational Policy / Administration	The impact of digitalization depends on institutional orientation toward sustainability; regulatory and strategic support is required	Integration of sustainability into strategic documents; standards for assessing leadership competencies; support for "green" digital transformation
Corporate Training / ESG Programs	The model is applicable for developing sustainable leadership competencies among employees	Digital simulations of strategic decisions; ESG metrics analysis; sustainability risk assessment platforms

The practical value of the model lies in its provision of a logical sequence for the development of sustainable leadership competencies through technology integration. Technologies are not viewed as an end in themselves within digitalization, but as a means of cognitive and value-based transformation.

The implementation of smart technologies should be accompanied by a strong institutional orientation toward sustainability, which enhances their impact on the development of systems thinking and strategic competencies.

6. Theoretical contribution of the study

This article extends research at the intersection of sustainable leadership, the digital transformation of education, and the competency-based approach in four key directions.

First, sustainable leadership is conceptualized not only as a managerial practice of incumbent leaders but also as an outcome of the educational process, formed through cognitive and value-based mechanisms.

Second, the article proposes a sequential mediated model explaining the influence of smart technology integration on sustainable leadership competencies through the following chain: systems thinking → environmental responsibility → strategic decision-making.

Third, institutional orientation toward sustainable development is introduced as a moderating variable, demonstrating that the effect of technologies depends on the strategic and value-based context of the educational organization.

Fourth, the article refines the competency-based approach by integrating cognitive, value-based, and behavioral dimensions into a unified theoretical framework that connects sustainable development, leadership, and digital technologies.

7. Research limitations and directions for future research

Despite the theoretical grounding of the proposed model, the study has several limitations that should be considered when interpreting the results and planning subsequent empirical research. As shown in **Table 5**, these limitations relate to the conceptual nature of the article, the operationalization of variables, contextual differences, unaccounted individual factors, design constraints, and the model's generalizability beyond the educational setting.

Table 5. Research limitations and future research directions

Limitation	Implication	Future research directions
Conceptual nature of the article	The model and hypotheses have not yet been empirically tested	Empirical validation using SEM/PLS-SEM; assessment of direct, indirect, and moderating effects
Operationalization of variables	Scales require adaptation to the digital education context; the understanding of "technology integration" may vary	Adaptation and validation of scales; refinement of indicators across different digital learning environments
Cultural and institutional differences	Context (country, digital maturity, organizational culture) may influence the strength of relationships	Cross-cultural and inter-institutional comparisons; multi-group analysis
Unaccounted individual factors	Personal and behavioral differences among learners are not included in the model	Inclusion of control variables (digital competence, participation in environmental initiatives, individual attitudes); testing alternative pathways
Design limitations (proposed)	A single cross-sectional design may not capture the dynamic development of competencies	Longitudinal studies; experimental designs; comparison of groups with varying levels of technology integration
Generalizability to the corporate context	The model is developed for education but may have broader applicability	Testing the model in corporate training and ESG programs; comparison of "education vs. business" contexts

8. Conclusion

This article demonstrates that smart technologies in education should not be viewed as neutral tools of

digitalization, but rather as resources for the development of sustainable leadership—primarily through the enhancement of cognitive and value-based mechanisms. Technologies strengthen the ability to manage complexity (data, scenarios, decision consequences), thereby supporting systems thinking. In turn, systemic understanding increases the likelihood of fostering environmental responsibility and transitioning toward strategic decision-making aligned with the logic of sustainable leadership.

At the same time, the effect of technologies depends on the institutional context. The orientation of an educational organization toward sustainable development amplifies the influence of technologies on the development of systems thinking, whereas in the absence of such an orientation, digital tools may remain limited to objectives related to efficiency and control.

Theoretically, this study refines the mechanism through which sustainable leadership competencies are formed within a digital educational environment. Practically, it provides guidance for designing programs in which technologies are intentionally used to develop systems thinking, environmental responsibility, and strategic behavior. Ultimately, the study highlights that the value of smart technologies lies not in their technical capabilities alone, but in their potential to reshape cognitive and value-based foundations of leadership in the context of global sustainability challenges.

Future research should empirically test the proposed model and assess its robustness across different institutional and cultural contexts.

Disclosure statement

The author declares no conflict of interest.

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