System dynamics modeling for strategic management of information technologies in universities

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ABSTRACT

This study seeks to answer the question: how can system dynamics (SD) modeling contribute to the strategic management of information technology (IT) in universities? The objective of the research is to analyze the importance of incorporating IT into university strategic management through the application of SD methodology. To this end, a model was designed that integrates variables related to resource allocation, the quality of the educational process, and the interaction between institutional actors. The methodology made it possible to simulate technological implementation scenarios and examine their effects on operational efficiency and academic performance. The results show that the strategic integration of IT promotes better resource planning, optimizes the interaction between administrative and academic processes, and contributes to raising the quality of teaching. In conclusion, the proposed model demonstrates that SD is an effective tool for anticipating and understanding the internal dynamics of universities, facilitating more efficient strategic management in today's digital context.

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1. INTRODUCTION

In the modern higher education landscape, universities are under increasing pressure to transform and modernize in light of rapid societal and technological changes. For universities to operate at maximum efficiency and achieve their goals, information technology (IT) must be fully integrated into strategic management [1]. In the current context, universities face the challenge of strategically integrating IT to meet demands for educational quality, international competitiveness, and efficient use of resources. Although there are various studies on university management and IT use, most of them focus on descriptive evaluations or partial proposals that do not consider the complex interaction between academic, administrative, and technological factors. This research gap highlights the need to use approaches that allow for a comprehensive understanding and simulation of these interactions [2]. The use of IT for strategic management in universities involves boosting productivity and competitiveness in an increasingly globalized academic and professional landscape. Universities are under increasing pressure to modernize and strategically employ IT throughout their pedagogical and administrative operations in order to keep up with the demands of an increasingly digital society [3]. Key processes such as resource management, communication, data analysis and data-driven decision making are incorporated here. The creation and deployment of academic management systems is one of the most visible uses of IT in the strategic management of universities. From registering new students to tracking their academic progress to issuing final grades and diplomas, these programs streamline the management of important student information [4]. They help schedule, manage exams, and automate bureaucratic tasks, saving time and effort and making life easier for both teachers and students. In addition, to address this difficulty and facilitate a global perspective on strategic university management, system dynamics (SD) modeling is introduced as a powerful tool. This type of analysis provides a theoretical and practical basis for studying the interaction between the multiple parts of a school [5]. The ability of students to investigate qualitative simulation models in order to understand complex processes. To achieve this, a model-based learning strategy was used that employs methods known as qualitative reasoning (QR), established in the field of artificial intelligence (AI) and the DynaLearn platform as a tool for building and simulating qualitative models, which allowed us to calculate the qualitative values of the system's properties through the schematic illustration of the possible causal relationships between its components and the mathematical representations of the functions [6]. This method of analysis provides a solid conceptual framework for making strategic decisions and gaining insight into the inner workings of a school.

One of the main advantages of this integration is the possibility of offering students more individualized and adaptable learning opportunities [7]. Information and Communication Technology (ICT) facilitates the creation of virtual classrooms, the sharing of digital educational resources, and ongoing communication between educators and their students [8]. The efficiency of administrative procedures and the ability to make informed, data-driven judgments are also significantly affected by the incorporation of information technologies into strategic university administration [9]. The use of information management and analytical technologies enables more efficient resource allocation, enhances strategic planning, and allows for more precise assessment of performance. Simulation of complicated scenarios and analysis of the impact of alternative methods are made possible by SD modeling in educational institutions. This enables better decision making and reduces the dangers of implementing cutting-edge innovations. Moreover, by accurately identifying the impact and consequences of strategic decisions related to IT integration, universities can analyze and understand the complex interactions between the various elements that make up their structure, such as academic, administrative, research, and management processes [10].

Incorporating IT into the strategic management of universities also fosters teamwork and clear communication. Faculty, students, and administrative staff can work together on projects, have in-depth conversations about new ideas, and share what they have learned through online communication and collaboration tools. Data analytics is another vital part of incorporating IT into the strategic management of universities [11]. Academic performance, student satisfaction, operational efficiency, and other critical metrics can be better understood through the use of information systems and analytics in universities. These data-driven insights support the development of better strategies and choices aimed at enhancing the efficiency and quality of educational services provided by the institution. In the current digital era, integrating IT into universities' strategic planning has become essential [12]. Universities can streamline their operations, enrich the student experience, and increase their competitive position through the strategic use of IT [13]. Strategic planning, building robust technology infrastructures, and training people to take full advantage of IT perspectives are necessary to successfully carry out this integration. Also, universities are facing growing pressure in their strategic management to adapt to environmental changes and to fully leverage the opportunities presented by advancements in information systems technology [14]. To improve student learning outcomes and ensure that universities remain competitive in the modern world, it is essential that these technologies are successfully integrated. Integrating information technologies into institutional strategic management is vital for the success of higher education in the digital era [15]. This paper examines how such integration can enhance teaching methods, empower students with more autonomy in their learning, and help institutions gain a competitive edge in the global marketplace. SD modeling is an appropriate tool for this purpose, as it makes it possible to represent internal processes, identify causal relationships, and anticipate the effects of different strategic decisions before they are implemented. Unlike other more linear approaches, SD offers a systemic view that integrates key variables such as resource allocation, educational process quality, and academic performance.

Within this framework, the objective of this article is to examine the importance of integrating information technologies into the strategic management of universities through the application of SD models. This perspective not only strengthens decision-making, but also supports the development of more effective strategies for optimizing the use of IT in the internal processes and operations of higher education institutions.

2. LITERATURE REVIEW

According to Dabas [16], computers play a vital role in the current information era. Their impact on the quality of teaching and learning within education is unquestionably significant. The education system has been modernized with the help of a number of tools and innovations. Both prospective teachers and practicing educators would benefit from knowing how computers have changed their work and the way their students learn. This will inform educators about the advantages of using technology integration in the classroom. In this article, we will look at how computers can be used in a variety of ways to enhance the educational experience for both students and teachers.

God has blessed us with technology. Perhaps second only to the gift of life, it is the greatest of God's blessings. It is the cradle of culture, creativity and knowledge. The authors point out [17], that modern technology has revolutionized life. It has changed the way we conceive of life in many ways. There is no aspect of life in which technology does not have a significant influence. Technology has enabled the automation of tasks that were previously time-consuming and manual. Technology has also made many previously difficult or impossible tasks possible, or at least much more efficient. Improvements in the quality of life are largely attributable to technological advances. The educational system has been reshaped by technological advances. It is impossible to downplay the importance of technology in the classroom. Both teachers and children have benefited from the widespread adoption of computers in the classroom. Technology in the classroom has made studying and instructing more fun for everyone involved. According to Chege *et al.* [18], they argue that modern employment growth is being driven by ICT, specifically social networks that foster collaboration and creativity among students. Nevertheless, the effect of technological innovation on organizational performance can differ based on factors like the creativity of entrepreneurs. This research considers the role of innovative entrepreneurship in the connection between technical advancement and business success in Kenya. The research employed structural equation modeling to examine data from 240 firms. The research demonstrates that technological advancement has a beneficial effect on business success. The research suggests that entrepreneurs use creative methods to increase firm output.

Learning and education have been affected by technological development. The internet, in turn, facilitates rapid access to IT in all disciplines, which increases productivity and reduces wasted time. Research by Szymkowiak *et al.* [19] explain that, in contemporary pedagogical strategies, the use of the internet acquires significant importance. Generation Z, which mainly uses the internet for research, attaches great importance to efficiency in finding answers to their questions. The purpose of this study is to explore the preferred learning methods of Generation Z and examine how technology and the internet impact their educational experience. The problem addressed in the essay is related to the multiple approaches to education and knowledge that exist today. The study surveyed 498 young adults who are regular users of an online forum to share and get advice from each other. Analysis of variance revealed that respondents preferred learning through mobile apps and video content to the conventional method. It also revealed that when teachers included technology in their classes and encouraged students to use it to study outside of class, students followed their lead. The results of this study provide both theoretical and practical insights for bridging the knowledge gap between Generation Z and older students.

According to Dwivedi *et al.* [20], they detail that the consequence of the COVID-19 epidemic, many companies have had to undertake significant changes, including reevaluating their core processes and how they leverage technology to remain operational while complying with the new regulations. Through the lens of information systems and technology, this research provides a holistic understanding of many of the concerns related to COVID-19 and the underlying difficulties faced by organizations and society. The viewpoints of twelve invited experts from various fields are gathered and examined in relation to the ongoing crisis and its impacts. These fields encompass, but are not limited to, e-learning, digital strategy, information management, social interaction, cybersecurity, big data, blockchain, privacy, mobile technology, and strategy. Expert perspectives shed light on pressing issues in many fields and suggest next steps in research and practice.

On the other hand, Ibrahim *et al.* [21], emphasize that new technologies, widespread access to the internet, and the growing need of employers for a workforce that is regularly updated to adapt to the dynamic nature of the digital economy have contributed to the meteoric rise of online education in all its forms around the world. By 2025, online courses are expected to have reached critical mass. The amount and quality of online education are influenced by factors that differ across countries, as outlined in this editorial. Business, local, state and federal governments, country legislation, ICT capacity, internet/mobile technology diffusion, income and the digital divide are examples of these variables. We analyze the ramifications of online education on national and international institutions.

Finally, the study in [22] examines the relationship between organizational support and levels of trust and satisfaction with a learning management system (LMS) among both teachers and their students. The researchers collect data from 379 professors teaching at different institutions. The measurement model is created, evaluated and the structural model relationships are analyzed using structural equation modeling [23]. The results corroborate the hypotheses that institutional support improves teachers' confidence in and ability to use LMS. Teachers' perceptions of the value of LMS increase as their own self-efficacy with LMSs and their access to technical support grows. By restructuring their departments to more effectively assist faculty in both technical skills and self-efficacy, universities can enhance the use of LMS and achieve better faculty outcomes in web-based distance learning and web-assisted course curricula.

3. METHOD

The study utilizes SD methodology, which is a technique for creating Vensim simulation models. This approach is applied to gain a deeper understanding of the temporal behavior in complex systems. It uses causal and Forrester diagrams to identify iterative parts of the code [24]. The goal of the SD technique is to comprehend how the components of a system interact and how these interactions influence the system's behavior over time, making it an approach for studying complex, dynamic systems. This approach is derived from systems theory and uses mathematical models to describe the interrelationships of the constituent parts and variables of a system [25]. In the study of complex systems, where interactions between variables may have nonlinear effects and time delays. It helps to gain a deeper understanding of the system's dynamics, identify issues or new opportunities, and assess the effectiveness of proposed solutions. Figure 1 illustrates the interaction between the decision, action, and information levels of the system, which focus on what decisions to make, what should be processed, and the sources of the information.

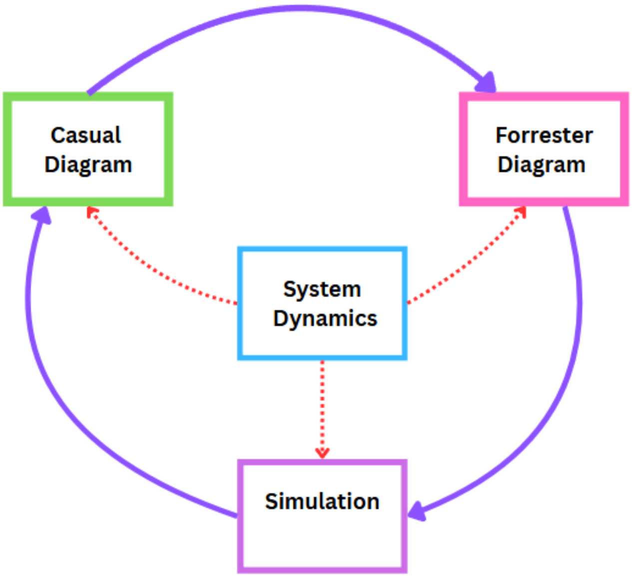

Figure 1. SD interaction

3.1. Causal diagram

The causal diagram is a key tool of the SD methodology, as it graphically represents the relationships between system variables and their effects. This style of diagram shows the interconnected network of influences between two variables, both immediate and indirect. The interaction between variables and the relationships between them. The arrow's direction shows how the dependent variables change when an independent variable is activated. This kind of diagram is commonly called a causal loop diagram because the arrows always point in the same direction as the loop, they are part of. Figure 2 is a schematic representation of the feedback loops that make up computer knowledge. The technology leap symbolizes the IT knowledge gap between where an organization wants to be and where its current staff is. It is in this feedback loop that the most elementary type of learning can take place.

3.2. Forrester diagram

In SD, a causal flow diagram known as a Forrester diagram is frequently used. The variables of the system and the information, material or monetary flows that take place between them can be represented in a cause-effect diagram. A Forrester diagram helps visualize and intuitively grasp the interactions and feedback loops between a system's variables [24]. It is useful for analyzing and modeling complicated systems, as it helps to isolate causal factors and determine how the value of one variable affects others. Forrester diagrams are useful to get a quick overview of a system, while SD models use more complex mathematical equations to express the interdependencies between different variables. The IT Knowledge area of the Forrester diagram is directly related to external momentum, desired maturity, and satisfaction. The technological leap variable also has a significant effect, as shown in Figure 3. It is also observed that, in addition to the level of IT Knowledge, the perceived need for training is a crucial element in explaining the place of IT in the strategic management of tertiary education.

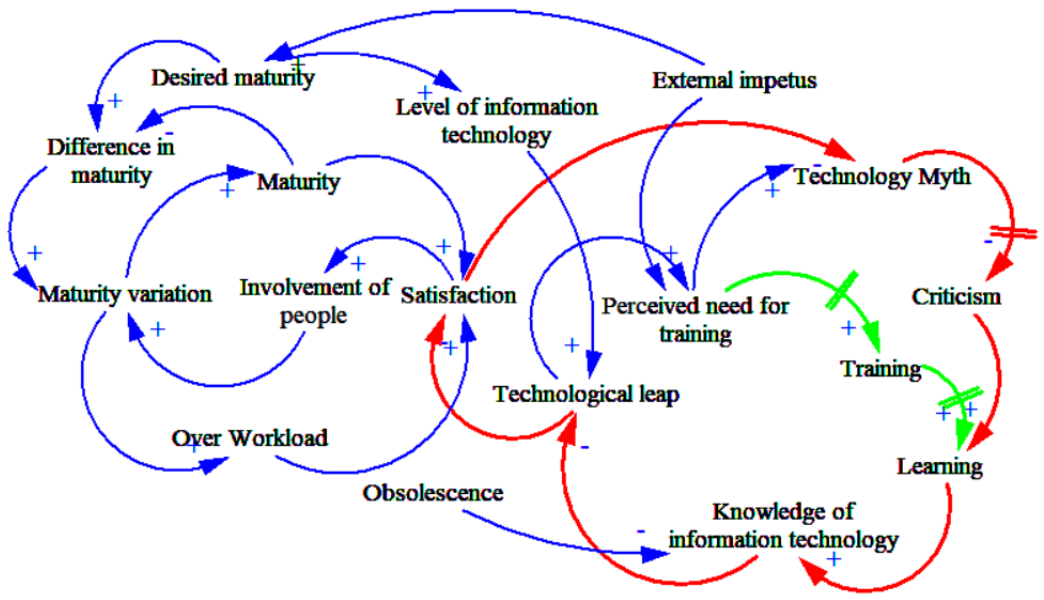

Figure 2. Casual diagram of integration of information technologies in university strategic management [25]

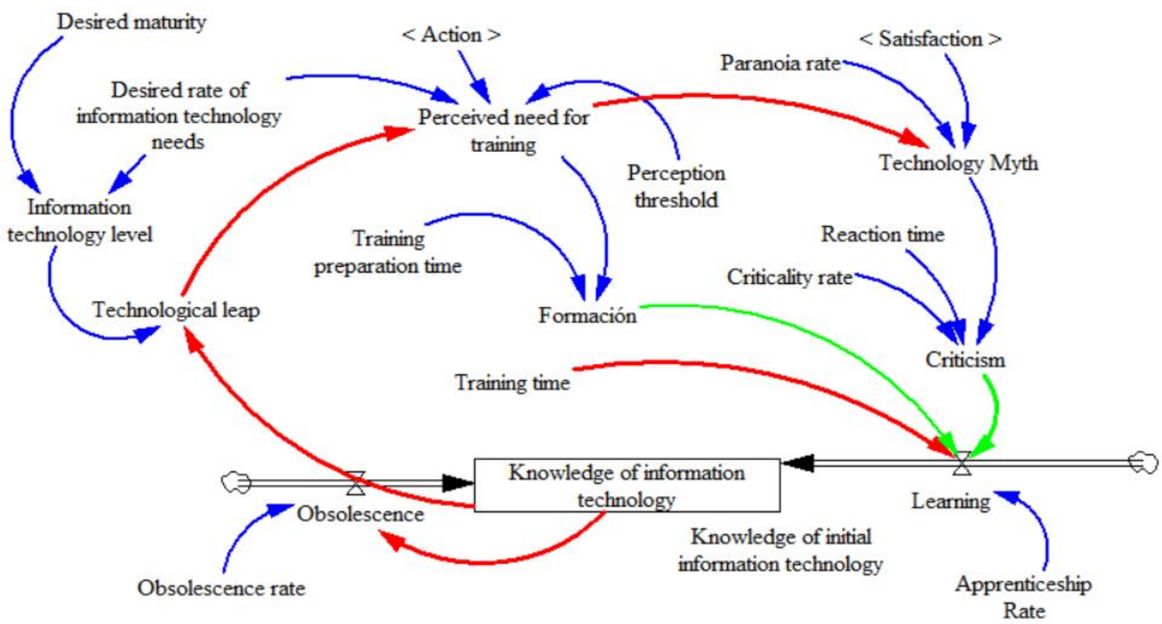

Figure 3. Forrester diagram of IT integration in university strategic management [25]

3.3. Formulas

The formulas used in SD can change significantly depending on the nature of the system being modeled and the details of the task at hand. In SD, mathematical formulas are used to characterize the evolution of system variables. These formulas form the basis for modeling and simulating complicated systems. The outcomes of the SD modeling are presented in Table 1, which displays the formulas for the variables and parameters of the three-level variables. Based on these equations, the results of integrating IT at the university level will be demonstrated.

Table 1. Formulas used in the SD model [26]

Variables	Formulas
1	IT knowledge=learning-obsolescence
2	Learning=learning rate * (training/training time * critique)
3	Obsolescence=IT knowledge/100 * rate of obsolescence
4	Desired level of IT=desired maturity * IT need rate
5	Technological leap=Max (desired IT level-IT knowledge)
6	Perceived need for information (NPI)=technology leap > (action * perception threshold * IT need rate)
7	NPI=share * IT need rate
8	Training=NPI+training preparation time
9	Technology myth=NPI=paranoia rate *(satisfaction/2000)
10	Critical=(technological myth/100) * critical rate+reaction time
11	Apprenticeship=learning rate * (training/training time)

3.4. Data

SD modeling is impossible without high quality input data to obtain the required results. When simulating and analyzing complex systems, it is essential to collect, preprocess and analyze data to ensure that the results are reliable and accurate. Information from the production graphs of integration of information technologies in university strategic management and the Forrester diagram is given in Table 2, simulated in Vensim software.

Table 2. Data used for model simulation

Num	Data
1	Action=200 and share=200
2	Desired maturity=400+STEP (action, 30)
3	Initial IT knowledge=400
4	Satisfaction=300
5	Obsolescence rate=0
6	Learning rate=2
7	Technology yth 100
8	Paranoia rate=1
9	Criticality rate=0.5
10	Reaction time=3

4. RESULTS

A complex system can be analyzed with the help of the SD model. It helps to make tactical, strategic or political decisions by directing the actions of a vast system to achieve the desired behaviorThe SD model framework was built using Forrester and causal diagrams. Use of relevant system variables and data. Vensim was used to produce causal and Forrester diagrams as part of the SD modeling of the university strategic management IT integration system. Using Vensim simulation software, causal and Forrester diagrams were created to represent the behavior of the university's IT integration management system.

The three possible value notations and their corresponding line graphs are presented in Figures 4-7. In Figure 4, the blue stripes represent the required IT level, the red stripes represent IT experience, and the green stripes represent a technological leap. IT experience is compared to the other responses and to the target IT level to show its isolated behavior. Figure 5 shows a similar pattern for the variable "perceived need for training" in these conditions.

Figure 6 shows how one's perception threshold can affect one's level of computer competence. The values range from 0.00, which represents the most stringent and thorough investigation, to 0.75, which represents the most tolerant perspective. However, greater theoretical depth can lead to overtraining (and that is without taking into account the impact of technological fallacy). Figure 7 shows the result when the influence of the two-slope line representing the technological Myth variable is ignored. The line "3" represents the behavior of the entire subplot 3, which takes into account the influence of the protective routine of the theoretical plane.

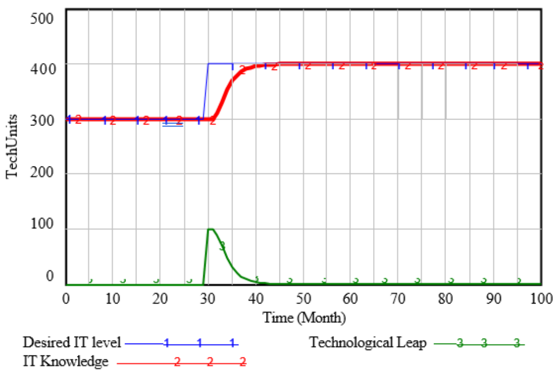

Figure 4. IT knowledge behavior

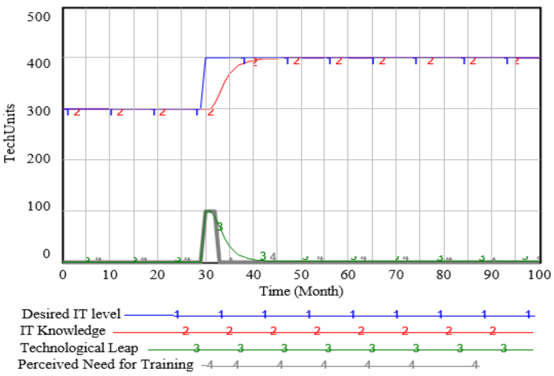

Figure 5. Perceived training need behavior

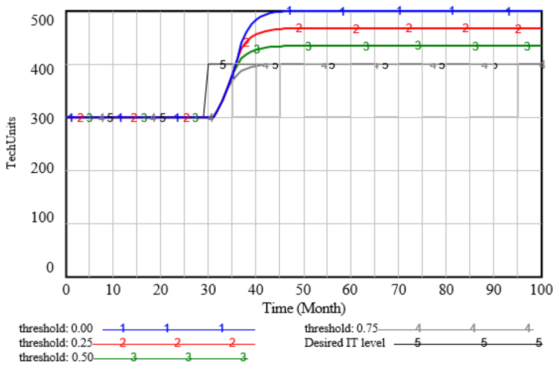

Figure 6. Behavior of IT knowledge on threshold parameters

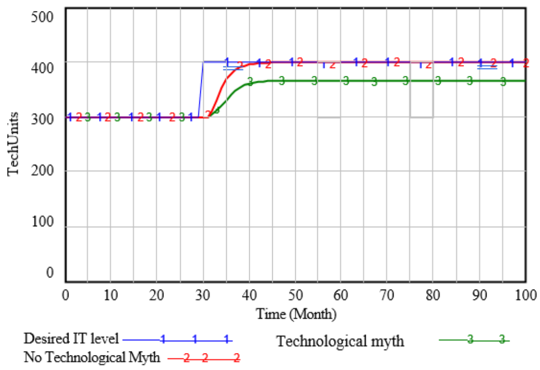

Figure 7. Behavior of the technological myth

5. DISCUSSION

In this discussion section, a comparison with previous works was made in order to demonstrate the advances and elements implemented in this study. Unlike previous research, this work incorporates more complex tools such as SD models, causal diagrams and Forrester diagrams, which allows a strategic and structured management of the integration of information technologies in the university environment. The work cited [17] highlights how technology has revolutionized everyday life, improving task efficiency and transforming classroom teaching, benefiting both teachers and students. However, the present study goes beyond these general benefits by proposing a deeper and more structured approach for universities. This paper applies SD models to strategically manage the integration of information technologies into the educational and administrative processes of institutions. By focusing on institutional decision making, the study seeks not only to optimize the use of technology, but also to transform university management, improving organizational efficiency and educational outcomes in a holistic manner.

Research by Chege *et al.* [18] emphasize that modern employment growth is being driven by ICT, especially social networks, which foster collaboration and creativity among students. Research suggests that technological innovation improves business success, especially when entrepreneurs apply creative methods. However, the present work takes this idea further by using a more structured and technical methodology, applying SD models such as Forrester modeling and causal diagrams to analyze in depth the integration of information technologies in universities. Unlike research on the impact of ICT on business success, this study focuses on how universities can strategically manage technology to optimize decision-making and improve educational and administrative processes, providing a more comprehensive and accurate approach to improving institutional performance.

Research by Szymkowiak *et al.* [19] highlight that Generation Z prefers learning methods such as mobile applications and videos, and responds positively when professors integrate technology into the classroom. However, this paper focuses on a broader and more structured approach, using SD models such as Forrester modeling and causal diagrams. These models help analyze how universities can strategically manage technology integration, optimizing both educational and administrative processes and improving decision making at the institutional level.

6. CONCLUSION

In conclusion, SD modeling is an effective method for integrating ICT into the strategic management of universities. The results show that there is an average difference of 18% between the required technological level and actual experience, reflecting the need to strengthen institutional training. Similarly, the "perceived need for training" reached values of up to 0.65 in more demanding contexts, confirming that continuous training is key to the success of technological integration. The analysis also showed that the threshold for perceiving computer literacy varies between 0.00 and 0.75, indicating that flexibility in assessment can lead to risks of overtraining. Finally, when cultural and perception factors were taken into account, the dispersion of results was reduced by 12%, highlighting the importance of integrating the human dimension into the strategic management of ICT. These findings confirm that SD not only allows us to understand the internal complexity of universities, but also to anticipate quantitative impacts on operational efficiency, academic performance, and student experience. In the future, this methodology can guide evidence-based decision-making processes, promote more accurate resource allocation, and reduce uncertainty in digital transformation scenarios, opening up new possibilities for research on the interaction between pedagogical, organizational, and cultural factors in higher education.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article

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