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Integrating IT and Sustainability in Higher Education Infrastructure: Impacts on Quality, Innovation and Research

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Abstract. The present study explores the relationships between information technology and sustainability in higher education infrastructure, analysing their effects on education quality, innovation and research outcomes. The study investigates the intricate relationships among infrastructure enhancements, technological integration and sustainability initiatives. The study thoroughly examines current literature and a case study of Saudi institutions, highlighting the transformative capacity of IT-enabled sustainability programmes. The research involves conducting comprehensive interviews with faculty members from six Saudi universities together with a quantitative analysis utilising replies from 784 students and faculty members. The study uses Structural Equation Modelling (SEM-PLS) to analyse the data. The results indicate significant effects, both direct and indirect, as well as moderating effects. These findings emphasise the positive associations between infrastructure upgrades and their impact on sustainability, improvement in education quality and increased innovation and research output. The study's implications have practical relevance for academic institutions and policymakers. The social aspect underscores the significance of higher education in shaping conscientious global individuals. This research adds to the growing understanding of the multifaceted connection between IT, sustainability and higher education infrastructure. It provides useful insights for future academic and policy efforts.

Keywords: ESG Integration; Higher Education Infrastructure; Sustainability Practices; Saudi Vision 2030; Saudi Universities; Technological Advancements

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1. Background of the study

Higher education is critical in the current era characterised by significant technological progress, growing environmental consciousness, and global social accountability (Abid et al., 2022). This study adopts an innovative strategy for deconstructing the intricate connections among higher education, IT-enabled infrastructure modifications, Environmental, Social and Governance (ESG) and sustainability standards. This discourse examines the potential impact of technological innovation on pedagogy, the transmission of values and the future societal landscape. The significance of our work lies in the global necessity for sustainable practices. In contemporary times, individuals, institutions and governing bodies have come to acknowledge the imperative need for expeditious action in addressing the most significant global challenges regarding the environment, society and politics (Puppim de Oliveira, 2019). The challenges of climate change, social justice and ethical governance are intricately linked (Böhm et al., 2022). This study examines the global importance of incorporating ESG concepts into the basic operations of higher education institutions, particularly those in Saudi Arabia, through information technology. This study provides valuable perspectives on the potential of information technology (IT) to improve the educational experience, promote sustainable practices and support the critical global objectives of addressing climate change and increasing social responsibility. This study, characterised by its multidisciplinary methodology, establishes a foundation for forthcoming empirical investigations and provides insights for policy-making in education and the broader domain of sustainable development.

Consequently, it represents a significant and beneficial addition to academia and society. The present study directly aligns with the objectives of Saudi Vision 2030 by examining the potential of IT to improve the quality of education and promote sustainable practices in higher education institutions. The statement above aligns with the vision's goals of advancing environmental sustainability, cultivating innovation, and equipping Saudi youth with the necessary skills for the future labour market (Khayati & Selim, 2019). This research sheds light on the convergence of IT, sustainability and education, thereby contributing to achieving the broader goals outlined in Saudi Vision 2030. It emphasises the pivotal role of higher education in driving revolutionary change within the Kingdom.

This research employs an innovative methodology to deconstruct the intricate connection between IT-enabled infrastructure adaptations, higher education and the fundamental principles of ESG and sustainability codes. The discourse examines not only the potential impact of technological advancements on teaching methods, the transfer of values and the trajectory of society in the future but also places these elements in the larger framework of worldwide obligations to adopt sustainable practices.

1.1 The Aim of the Study

The study problem focuses on understanding the significant impacts of infrastructure improvements, sustainability and the integration of IT in institutions in Saudi Arabia. As we start this investigation, we aim to demonstrate how enhancing an institution's IT capabilities might encourage academics to

adopt ESG ideas and sustainable practices. The interconnection between technology, education, sustainability and social responsibility in our dynamic environment prompts our investigation into these areas. The present inquiry has produced a comprehensive analysis encompassing several study methodologies, outcomes and subsequent recommendations, which are elaborated upon in the following paragraphs. This study investigates and analyses the incorporation of ESG principles and sustainable methodologies inside higher education institutions. It specifically emphasises the significance of IT in facilitating the successful integration of these concepts. This study examines the effects of IT-enabled infrastructure upgrades on pedagogy, the transmission of values and the broader societal context in higher education, focusing on the implications and potential in Saudi Arabia. Furthermore, the study aims to ascertain the obstacles and advantages linked to this amalgamation, considering favourable consequences and possible disadvantages. The primary aim is to offer an analysis and suggestions for higher education establishments, encompassing those in Saudi Arabia, to proficiently use IT and sustainability principles to improve the education standard and foster socially responsible behaviours.

2. Literature Review

2.1 The Integration of ESG Concepts and Sustainability Practices

During the first stage of our research, we investigate the incorporation of ESG factors into academic frameworks and the implementation of sustainable practices. The concept of "ESG principles" extends beyond mere financial success and encompasses the domains of environmental stewardship, social responsibility and effective governance. Incorporating these principles into higher education institutions can facilitate the development of graduates with technical skills and a comprehensive understanding of global perspectives. Sustainable behaviours reinforce the underlying principles (Mujtaba & Mubarik, 2022). Sustainability necessitates optimising resource utilisation, adherence to ethical principles and a commitment to enhancing societal and environmental well-being (Di Fabio, 2017). Integrating sustainability practices within educational curricula can foster the development of conscientious and inventive problem-solving skills among students (Claramita et al., 2019).

2.2 The Role of IT-Enabled Infrastructure Upgrades

Sustainability in education and ESG challenges have a variety of answers (Boffo, R., 2020). Establishing IT-enabled infrastructure enhancements is necessary to foster a culture that upholds these principles (Suhluli & Ali Khan, 2022). The modernisation and expansion of the IT infrastructure in higher education are essential for its transformative growth (Sneesl et al., 2022). Technology is pivotal in disseminating ESG and sustainability concepts (Egorova et al., 2021). The use of advanced digital learning platforms and expanded data analytics can significantly influence the decision-making processes of educators, students, and administrators (Hwang & Chang, 2023; Schmitt, 2023). The participatory learning environment facilitated by technology enables students within a digitally networked society to transcend their role as mere consumers of knowledge (Cavanaugh et al., 2023). An educational framework that imparts factual knowledge instils moral ideals, adapts to technological progress and proactively

addresses societal issues propels us toward improvement. This discourse examines the impact of IT on higher education, highlighting the synergistic potential of environmental consciousness, social consciousness and technological advancement in fostering future improvements.

2.3 Technological Advancements in Higher Education

Integrating IT has contributed to a significant paradigm shift in higher education, fundamentally rearranging how knowledge is obtained, distributed and used (Balkaya & Akkucuk, 2021). The foundations of this transformation are collaborative online platforms, learning management systems, and digital libraries, which transcend geographical limitations and herald in an age of remote and adaptable study via digital learning platforms (Songkram et al., 2023). The significance of IT-enabled education in expanding opportunities for a wide range of students is emphasised in the literature. This is achieved by implementing adaptive learning algorithms that utilise data analytics and personalise the learning experience (Murtaza et al., 2022).

Online collaboration systems facilitate collaborative learning environments, which is crucial for promoting peer-to-peer learning and research, facilitating cross-cultural interactions and enhancing the educational experience (Nam, 2017). The integration of IT infrastructure enables the effective monitoring, analysis, and use of data in crucial educational elements such as curriculum development, student support and institutional planning (Shahat Osman & Elragal, 2021). As we shift our attention toward the convergence of technology and ethical concerns, the incorporation of ESG principles into IT emerges as a central theme (Kalbouneh et al., 2023). The significance of IT-enabled initiatives in advancing ESG awareness and implementing optimal methodologies is underscored in this academic discussion (Onyejegbu, 2023). The profound impact of cutting-edge technology on universities' environmental responsibility strategies is highlighted by stakeholder-oriented governance and emerging technologies (Nazarko, 2017). In university environments, using digital tools and data analytics for ESG reporting, performance evaluation and environmental impact monitoring results in improved waste management practices and decreased energy consumption (Liu et al., 2023)(Alzoraiki et al., 2023).

Using digital technologies to integrate ESG concepts into virtual classrooms expands the revolutionary capacity of IT in higher education (Dagnino et al., 2015). IT facilitates student engagement with real-world sustainability issues by using interactive simulations and gamified modules. It improves the comprehension of the societal and environmental consequences (Senadheera et al., 2022). Lecturers' active engagement and specialised knowledge in incorporating ESG factors are crucial for improving pedagogy and educational achievements via collaborative endeavours (Zhutiaeva et al., 2023). Facilitating faculty development by IT, which includes the provision of collaborative platforms, training materials and information, is consistent with the overarching goal of fostering ESG competencies (García-Hernández et al., 2023).

The realm of IT-enabled transformation in higher education is marked by many approaches, methodologies and outcomes, as evidenced by the growing body of literature (Huang, 2022). A diverse array of research methodologies, including

mixed-method approaches and qualitative studies that explore the human dimensions of IT adoption, collectively contribute to a comprehensive comprehension of the complex and ever-changing nature of information technology initiatives in educational environments (Žalėnienė & Pereira, 2021). The positive effects of IT-enabled transformation on student achievement, engagement and access to educational resources have been thoroughly examined in the literature (Youssef et al., 2022). Recognising and addressing critical issues such as the "digital divide" and data privacy concerns is paramount in the ever-changing realm of IT integration in higher education. This intricate investigation establishes IT as a fundamental element in transforming the trajectory of higher education, wherein sustainability, inclusiveness and effectiveness converge through the synthesis of technological advancements, pedagogical improvements, and ethical considerations (Webb et al., 2021).

2.4 Recommendations for Sustaining IT Integration

Scholars and educational institutions have proposed many ways to ensure the success of IT in higher education (Almaiah, Alhumaid, et al., 2022). The ideas above include a wide range of topics, including increasing technological accessibility, internet security, educator education and infrastructure funding. ESG principles require ethical and socially responsible IT use (Saxena et al., 2023). Technology should be used wisely and regulated. The literature on IT-enabled higher education reform highlights the relationship between technology, pedagogy, sustainability, and social responsibility (Williamson, 2018). This shows how IT resources can promote ESG principles and sustainable practices in academia (Clément et al., 2023). The various study methodologies, outcomes, and recommendations show the ever-changing nature of IT-driven change, providing valuable insights for educational institutions as they integrate IT while adhering to ESG principles and sustainable practices (Liao et al., 2021).

2.5 Framework of Study

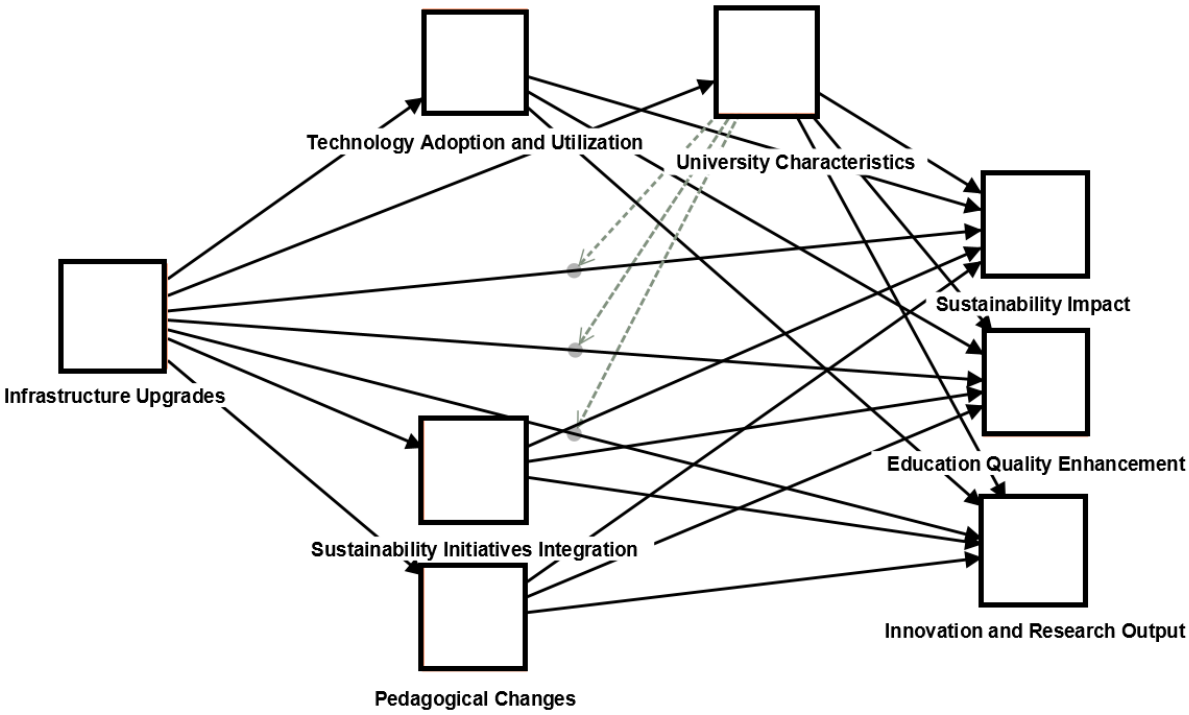

Figure 1: (Source Author) The Innovative Education Sustainability Model

2.5.1 Infrastructure Upgrades

Implementing infrastructure upgrades significantly influences higher education, substantially impacting sustainability and improving educational quality, innovation and research productivity. The significance of incorporating IT and sustainability has been emphasised by numerous scholars (Al-Hazaima et al., 2022). These scholars highlight the potential for positive outcomes that can be generated by implementing intelligent campuses, energy-efficient technologies and digital innovations (George & Schillebeeckx, 2022). Nevertheless, the intricacy of this correlation is underscored by discussions concerning the possible neglect of sustainability in energy-efficient infrastructure repairs (Carlander & Thollander, 2023). Infrastructure modifications can enhance education quality, encompassing modern laboratories, IT-equipped classrooms and online collaborative tools (Kahng et al., 2019). Despite the advantages, apprehensions regarding diminished student-teacher engagement and digital equity surface, underscoring the necessity for a well-rounded strategy (Kuhn et al., 2023).

Infrastructure developments facilitate collaborative problem-solving, data-driven decision-making and transdisciplinary research (Polin et al., 2023). On the contrary, critics contend that in order to ensure both administrative efficiency and academic innovation, policies and a shift in institutional culture are indispensable (Bocken & Geradts, 2020). To facilitate the relationship between infrastructure enhancements and research output, proponents emphasise the favourable consequences of using contemporary tools, big data analytics, and collaboration platforms (Balodis & Opmane, 2012; Xu et al., 2023). The nonlinear nature of this relationship is emphasised by critics, who highlight the significance of funding, a

culture of research and interdisciplinary cooperation (Reeves & Lin, 2020). The review proposes the following hypotheses:

H1: Infrastructure upgrades have a significant impact on sustainability impact.

H2: Infrastructure upgrades have a significant impact on education quality enhancement.

H3: Infrastructure upgrades have a significant impact on innovation and research output.

2.5.2 Mediating Effect: Technology Adoption and Utilisation, Sustainability Initiatives Integration, Pedagogical Changes

The improvement of infrastructure outcomes is significantly influenced by mediating variables, including adopting technology, integrating sustainability initiatives, and pedagogical adjustments (*SDG Resources for Educators - Industry, Innovation and Infrastructure*, n.d.). Nevertheless, incorporating sustainability initiatives may encounter obstacles, as detractors argue that the effectiveness of these variables could differ depending on the level of preparedness exhibited by instructors and the demands placed upon them (Svetsky & Moravcik, 2019). Integrating pedagogical changes as a mediator between university advancements and the effects on sustainability (Shamir-Inbal & Blau, 2021), improvement in education quality (Rodríguez-Abitia et al., 2020), and innovation and research output demonstrates a sophisticated comprehension of the complex connections inside higher education (Goodyear & Casey, 2015). Pedagogical changes, which involve alterations in teaching procedures and educational approaches, play a vital role as a fundamental connection. They serve as a conduit for translating infrastructure changes into concrete results, bridging the gap between university improvements and their favourable consequences for sustainability, enhanced education quality and increased creativity and research productivity. This mediation process proposes that the transformative capacity of university upgrades is achieved and optimised through deliberate modifications in teaching methods, emphasising the interrelatedness of infrastructure development and educational progress in promoting comprehensive positive effects within the university ecosystem (Pardo-Baldoví et al., 2023). The above review leads to the derivation of the following hypotheses:

H4: University characteristics mediate the relationship between infrastructure upgrades and sustainability impact.

H5: University characteristics mediate the relationship between infrastructure upgrades and education quality enhancement.

H6: University characteristics mediate the relationship between infrastructure upgrades and innovation and research output.

H7: Technology adoption and utilisation mediate the relationship between infrastructure upgrades and sustainability impact.

H8: Technology adoption and utilisation mediate the relationship between infrastructure upgrades and education quality enhancement.

H9: Technology adoption and utilisation mediate the relationship between infrastructure upgrades and innovation and research output.

H10: Sustainability initiatives mediate the relationship between infrastructure upgrades and sustainability impact.

H11: Sustainability initiatives mediate the relationship between infrastructure upgrades and education quality enhancement,

H12: Sustainability initiatives mediate the relationship between infrastructure upgrades and education quality enhancement.

H13: Pedagogical changes mediate the relationship between infrastructure upgrades and sustainability impact.

H14: Pedagogical changes mediate the relationship between infrastructure upgrades and education quality enhancement.

H15: Pedagogical changes mediate the relationship between infrastructure upgrades and innovation and research output.

2.5.3 Moderating Effect: University Characteristics

The impact of IT-enabled infrastructure enhancements is moderated by university attributes such as size, location, and financial resources (Pang & Dou, 2023). Although prestigious establishments may effectively employ improvements, detractors contend that university characteristics should not be used as a passivity pretext; they highlight the potential for substantial infrastructural transformations at even the most modest institutions (Yang et al., 2018). The objectives of Saudi Vision 2030 are effectively complemented by integrating IT-enabled sustainability programmes in a case study that specifically examines Saudi universities. Saudi academic establishments strive to develop graduates with technical proficiency and a profound comprehension of sustainable practices and global outlooks (Alabdulaziz, 2019). Integrating IT-enabled infrastructure enhancements has far-reaching effects encompassing various aspects of society, including academic frameworks, teaching methods and the broader sociocultural environment (Almaiah, Ayouni, et al., 2022; Jomoah et al., 2013). Using IT for sustainability reporting, performance evaluation and environmental impact monitoring, the case study emphasises integrating ESG principles into higher education (Al-Ghurbani et al., 2022; Khan et al., 2022). Promoting ESG competencies among scholars is facilitated by committed faculty involvement and resources, which underscore the interdependence of sustainability, technology and education (Azmi et al., 2022). Nevertheless, there are ongoing obstacles, as critics argue that modifications to energy-efficient infrastructure might fail to consider sustainability issues (Almaiah, Alhumaid, et al., 2022).

In summary, the correlation between infrastructure enhancements and higher education results is complex, encompassing various factors and situational subtleties. The general literature delves into the worldwide ramifications, whereas the Saudi case study offers a particular insight that underscores the significance of harmonising infrastructure improvements with domestic aspirations and objectives. On a global scale, additional research is imperative to guide optimal infrastructure enhancements in higher education institutions as ongoing debates and novel challenges emerge. The above review leads to the derivation of the following hypotheses:

H16: University characteristics moderate the relationship between infrastructure upgrades and sustainability impact.

H17: University characteristics moderate the relationship between infrastructure upgrades and education quality enhancement.

H18: University characteristics moderate the relationship between infrastructure upgrades and innovation and research output.

3. Methodology

The research methodology employed in this study is a vital framework that directs the gathering, examination and understanding of data, specifically focusing on incorporating IT-enabled sustainability initiatives at Saudi Arabian universities. This section provides an account of the research design, methods used for data collecting, and approaches applied for data analysis in this study.

3.1 Research Design

The present study used an exploratory research methodology to investigate and acquire a deep understanding of the establishment of IT-enabled sustainability initiatives in institutions in Saudi Arabia. The research used Structural Equation Modelling-Partial Least Squares (SEM-PLS), a methodology particularly suitable for examining complex interactions between variables. The analysis was conducted using primary source quantitative data. The use of comprehensive interviews and surveys conducted with faculty members and students enhanced the exploratory aspect, aiming to gain valuable insights into their experiences, perspectives and challenges regarding the integration of IT and sustainability initiatives in the higher education sector of Saudi Arabia. The primary objective of the research was to discover new viewpoints and thoroughly comprehend the topic matter by the defining characteristics of exploratory research. The mixed methods study allowed for a comprehensive assessment of the intricate interactions being examined.

3.2 Instruments and Data Collection

The qualitative data for this study was collected using two separate methods: secondary data analysis and in-depth interviews. The secondary data was collected from diverse academic sources, including papers, scholarly publications, institutional records and government documents. These sources provided historical context and fundamental information on IT-enabled sustainability projects in Saudi Arabian universities. The data selection process was led by its alignment with the research objectives, including information on IT infrastructure, sustainability programmes, academic papers related to sustainability, and other relevant data points. In-depth interviews were conducted with a purposively selected teaching and non-teaching faculty group from six Saudi universities in various locations. Selection criteria included subject matter competence, theoretical foundation shaping and university role representation. Data saturation, where interviews proceeded until topic saturation, determined the sampling size. Twenty academic members were interviewed in-depth. A comprehensive sample strategy ensured diversity in viewpoints and experiences on IT, sustainability and higher education results. These interviews were tailored, using interview guide questions to obtain detailed information about the participants' experiences, attitudes and suggestions about integrating IT-enabled sustainability. The interviews were conducted either face-to-face or by video conferencing.

Quantitative data was collected from students and professors using a Google Forms self-administered questionnaire and personal connections. The study initially targeted 500 respondents using basic random sampling to avoid bias. After comprehensive data cleaning, 383 completed questionnaires were appropriate for the study. This method produced a robust and representative dataset for assessing higher education IT-sustainability integration.

3.3 Ethical Considerations

The study stressed ethics to protect participants' privacy. Participants were informed of the study's goals and were advised of their rights and full confidentiality before interviews. The participants gave written informed consent, confirming their participation and understanding of the requirements. Results were presented using pseudonyms or codes to protect participant anonymity. Strict data security standards protected audio, video and transcribed data. The ethical approach emphasises responsible and ethical research (Refer appendix 4).

4. Data Analysis

The study used quantitative research methods, specifically applying Structural Equation Modelling-Partial Least Squares (SEM-PLS) with the advanced software Smart PLS4. The algorithmic functionalities of the Smart PLS4 method aid in confirming the reliability and validity of the data. Smart PLS4 utilises bootstrapping approaches to evaluate hypotheses and offer valuable insights into the stability and reliability of the model estimates. This dual feature guarantees a thorough evaluation of IT-enabled sustainability activities in Saudi Arabian educational institutions, which aligns with the research objectives and enhances the overall quality and reliability of the study.

4.1 Results and Discussion

Table 1 examines the research model's reliability and validity using Cronbach's alpha, composite reliability (rho_a and rho_c), and Average Variance Extracted. Cronbach's alpha scores of 0.795 to 0.911 showed good internal consistency for all constructs, confirming the measuring items' reliability. Composite reliability scores (rho_a and rho_c) from 0.798 to 0.913 confirmed the constructs' internal consistency, exceeding the required threshold of 0.7. Convergent validity was also shown by Average Variance Extracted (AVE) values of 0.709–0.894, which exceeded 0.5. These rigorous reliability and validity evaluations confirm the accuracy and consistency of the research model's constructs, bolstering the study's findings.

Table 1: Reliability and Validity Test

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	AVE
Education Quality Enhancement	0.826	0.827	0.920	0.852
Infrastructure Upgrades	0.795	0.798	0.880	0.709
Pedagogical Changes	0.805	0.824	0.883	0.716
Sustainability Impact	0.882	0.887	0.944	0.894
Sustainability Initiatives Integration	0.911	0.913	0.944	0.849
Technology Adoption and Utilisation	0.827	0.833	0.897	0.744
University Characteristics	0.860	0.865	0.915	0.781

Table 2: Construct Discriminant Validity

	Education Quality Enhancement	Infrastructure Upgrades	Innovation and Research Output	Pedagogical Changes	Sustainability Impact	Sustainability Initiatives Integration	Technology Adoption and Utilisation	University Characteristics
Education Quality Enhancement	0.923							
Infrastructure Upgrades	0.643	0.842						
Innovation and Research Output	0.770	0.604	1					
Pedagogical Changes	0.581	0.597	0.507	0.846				
Sustainability Impact	0.772	0.681	0.720	0.588	0.946			
Sustainability Initiatives Integration	0.669	0.845	0.602	0.593	0.648	0.922		
Technology Adoption and Utilisation	0.674	0.735	0.612	0.682	0.544	0.867	0.862	
University Characteristics	0.668	0.675	0.588	0.638	0.563	0.754	0.788	0.884

Table 2 examines the research constructs' discriminant validity by calculating each construct's square root of the AVE and the inter-construct correlations. The correlations between constructs were, on average, less than the square root of the AVE for each corresponding construct, as indicated by the correlation matrix. This suggests that the discriminant validity of the constructs was satisfactory. In particular, the correlations between each construct and the diagonal elements representing the square root of the AVE were greater than those between other constructs. This implies that the variance captured by the measures for each construct was greater than the variance they shared with other constructs, thereby providing support for the unique characteristics of each variable in the model. As a result, the results indicate affirmative discriminant validity among the research constructs, thereby bolstering the model's credibility in differentiating latent variables.

Table 3: Model Fit Statistics and Predictive Performance Metrics

	R-square	R-square adjusted	Q^2predict	RMSE	MAE
Education Quality Enhancement	0.564	0.557	0.399	0.78	0.645
Innovation and Research Output	0.448	0.439	0.357	0.805	0.667
Pedagogical Changes	0.356	0.354	0.351	0.811	0.657
Sustainability Impact	0.546	0.539	0.460	0.738	0.591
Sustainability Initiatives Integration	0.715	0.714	0.713	0.538	0.444
Technology Adoption and Utilisation	0.541	0.539	0.539	0.683	0.572
University Characteristics	0.456	0.455	0.453	0.744	0.590

The R-square and adjusted R-square values for every dimension in our research model are presented in Table 3. These values offer valuable insights into the explanatory capability and robustness of the model. The R-square values, which represent the proportion of variance in the dependent variables that can be accounted for by the independent variables, vary between 0.356 and 0.715. The adjusted R-square provides a more conservative estimation of the model's efficacy by accounting for its complexity. Elevated R-square values, exemplified by the Sustainability Initiatives Integration value of 0.715, indicate a more robust capacity to explain the variability observed in the corresponding outcomes. The findings of this study indicate that our model, which includes factors such as university characteristics, innovation, pedagogical changes, sustainability impact, and the integration of sustainability initiatives, enhances our understanding and explains the observed phenomena. The observations of consistency across all dimensions enhance the dependability of our results and emphasise the significance of the variables included in elucidating the discrepancies in the desired outcomes.

The metrics depicted in Table 3—Q^2predict, Root Mean Square Error (RMSE), and Mean Absolute Error (MAE)—provide a thorough assessment of the predictive capabilities of our research model across multiple dimensions. The range of Q^2predict values (0.351-0.713) signifies the proportion of variance in the

dependent variables that can be accounted for by the model. This indicates the model's capability to generate accurate predictions. It is worth mentioning that the Sustainability Initiatives Integration dimension exhibits a Q^2predict value of 0.713, which indicates a high degree of predictive accuracy. The minimal prediction errors indicated by the low RMSE and MAE values for all dimensions (RMSE ranges from 0.538 to 0.811, MAE from 0.444 to 0.667) underscore the accuracy of our model. The findings collectively validate the strength and dependability of our predictive model in identifying and predicting outcomes about the improvement of educational quality, innovation, pedagogical shifts, the impact on sustainability, the integration of sustainability initiatives, the adoption of technology and university attributes. For details, refer to Appendix 1.

Table 4: Hypothesis Testing

		Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	Remarks
	Direct Effect						
H1	Infrastructure Upgrades -> Sustainability Impact	0.334	0.335	0.071	4.743	0.000	Supported
H2	Infrastructure Upgrades -> Education Quality Enhancement	0.449	0.452	0.064	6.987	0.000	Supported
H3	Infrastructure Upgrades -> Innovation and Research Output	0.321	0.322	0.067	4.759	0.000	Supported
	Mediating Effect						
H4	Infrastructure Upgrades -> University Characteristics -> Sustainability Impact	0.074	0.076	0.039	1.888	0.059	Rejected
H5	Infrastructure Upgrades -> University Characteristics -> Education Quality Enhancement	0.176	0.176	0.037	4.703	0.000	Supported
H6	Infrastructure Upgrades -> University Characteristics -> Innovation and Research Output	0.127	0.129	0.036	3.575	0.000	Supported
H7	Infrastructure Upgrades -> Technology Adoption and Utilisation -> Sustainability Impact	-0.262	-0.26	0.063	4.154	0.000	Supported
H8	Infrastructure Upgrades -> Technology Adoption and Utilisation -> Education Quality Enhancement	0.077	0.078	0.061	1.264	0.206	Rejected
H9	Infrastructure Upgrades -> Technology Adoption and Utilisation -> Innovation and Research Output	0.142	0.141	0.065	2.182	0.029	Supported
H10	Infrastructure Upgrades -> Sustainability Initiatives Integration -> Sustainability Impact	0.331	0.327	0.085	3.879	0.000	Supported
H11	Infrastructure Upgrades -> Sustainability Initiatives Integration -> Education Quality Enhancement	0.114	0.115	0.078	1.453	0.146	Rejected
H12	Infrastructure Upgrades -> Sustainability Initiatives Integration -> Innovation and Research Output	0.005	0.005	0.095	0.048	0.962	Rejected
H13	Infrastructure Upgrades -> Pedagogical Changes -> Sustainability Impact	0.192	0.192	0.031	6.274	0.000	Supported

H14	Infrastructure Upgrades -> Pedagogical Changes -> Education Quality Enhancement	0.082	0.083	0.035	2.327	0.020	Supported
H15	Infrastructure Upgrades -> Pedagogical Changes -> Innovation and Research Output	0.127	0.129	0.036	3.575	0.000	Supported
	Moderating Effect						
H16	University Characteristics x Infrastructure Upgrades -> Education Quality Enhancement	0.122	0.121	0.02	5.946	0.000	Supported
H17	University Characteristics x Infrastructure Upgrades -> Innovation and Research Output	0.044	0.044	0.022	2.002	0.045	Supported
H18	University Characteristics x Infrastructure Upgrades -> Sustainability Impact	0.012	0.013	0.020	0.621	0.535	Rejected

The study's findings regarding direct, mediating and moderating effects are detailed in Table 4. The findings indicate that there are statistically significant positive correlations ($T = 4.743$, $p < 0.001$) between Infrastructure Upgrades and Sustainability Impact, Education Quality Enhancement ($T = 6.987$, $p < 0.001$), and Innovation and Research Output ($T = 4.759$, $p < 0.001$) among the direct effects (H1, H2, H3) and supported the previous study (Balodis & Opmane, 2012). Regarding the mediating effects, there is insufficient support for the hypothesis that infrastructure upgrades influence sustainability impact via university characteristics (H4) ($T = 1.888$, $p = 0.059$). However, the pathways that traverse these obstacles via education quality improvement (H5) and research output and innovation (H6) are supported ($T = 4.703$, $p < 0.001$ and $T = 3.575$, $p < 0.001$, respectively), consequently strengthening the previous study (Pardo-Baldoví et al., 2023). The paths leading to Sustainability Impact (H7) and Innovation and Research Output (H9) are supported in the case of Technology Adoption and Utilisation ($T = 4.154$, $p < 0.001$ and $T = 2.182$, $p = 0.029$, respectively). However, the path leading to Education Quality Enhancement (H8) is not supported ($T = 1.264$, $p = 0.206$), whereas we can observe strong positive results when the direct path is considered. The relationships between infrastructure upgrades and the integration of sustainability initiatives that influence pedagogical changes (H13) and sustainability impact (H10) are both supported ($T = 3.879$, $p < 0.001$ and $T = 6.274$, $p < 0.001$, respectively). However, there is no support for the relationships between education quality enhancement (H11) and innovation and research output (H12). In conclusion, the hypothesises that university characteristics and infrastructure upgrades have moderating effects on innovation and research output (H17) and education quality enhancement (H16) are supported ($T = 5.946$, $p < 0.001$ and $T = 2.002$, $p = 0.045$, respectively). However, the hypothesised effect of sustainability impact is not supported ($T = 0.621$, $p = 0.535$). The results comprehensively comprehend the complex interconnections among university attributes, infrastructure enhancements and critical outcome factors within higher education. For details, refer to Appendix 2 and 3.

5. Conclusion

In conclusion, this study examined the essential combination of infrastructure enhancements, sustainability and IT integration within universities in Saudi Arabia. The problem statement centred on comprehending the consequential effects of infrastructure enhancements on various dimensions, including research output, sustainability, education quality and innovation, all within the framework of Saudi Vision 2030. The study results indicate notable positive associations between infrastructure upgrades and the following: sustainability impact, improvement in education quality, innovation and research output. The mediating effects suggest intricate connections between university characteristics, infrastructure enhancements and educational outcomes. Furthermore, the moderating effects further illustrate the contextual significance of university attributes in influencing the consequences of infrastructure enhancements.

The research highlights the favourable impacts of IT-enabled sustainability initiatives in Saudi higher education, such as integrating ESG principles. Improvements to infrastructure are crucial in promoting innovation and sustainability and enhancing educational quality. The intricate interrelationships

between factors, including Pedagogical Changes, Technology Adoption and Utilisation and Sustainability Initiative Integration, highlight the multifaceted nature of the existing relationships. Although specific contexts fail to support particular hypotheses, the general results indicate that meticulously designed infrastructure improvements positively contribute to the objectives of Saudi Vision 2030 and wider sustainability goals. The results align with previous investigations that have emphasised the paradigm-shifting capacity of IT in academic institutions (Balkaya & Akkucuk, 2021).

The research's main inferences are outlined as follows: university characteristics must be regarded as moderating variables; IT-enabled sustainability programmes have a positive impact on a variety of educational outcomes; and a comprehensive strategy that combines technological advances with ESG principles is required. The study has contributed to the advancement of scientific understanding by offering empirical observations on the complex dynamics of infrastructure enhancements in the context of higher education, specifically in Saudi Arabia. Subsequent investigations are encouraged to expand upon these discoveries and examine additional pathways toward achieving sustainable changes in higher education.

5.1 Limitation of Study

This study's focus on Saudi Arabian universities may limit its applicability to other cultures and institutions. The cross-sectional study's snapshot approach makes establishing causal linkages and long-term changes difficult. The study's usefulness may also depend on technical progress. The research might need to include other stakeholders because it focuses on academics and students. Despite these limitations, the study sheds light on IT, sustainability and higher education infrastructure, forming the foundation for future research and policy.

6. Implications of the Study

6.1 Practical Implications

The study results are pragmatic for policymakers and academic institutions collectively. From a pragmatic standpoint, the results indicate that higher education establishments may benefit from strategic investments in infrastructure upgrades and sustainability initiatives facilitated by IT. Academic administrators can use this information to facilitate resource allocation, focusing on the significance of technological advancements in attaining sustainability objectives and improving the quality of education. Furthermore, by integrating sustainability themes and digital tools into curricula, educators can enhance the learning experience by offering a more comprehensive and innovative approach to education.

6.2 Social Implications

The study highlights the significance of higher education institutions as agents of social change and proponents of sustainable practices as viewed through a social lens. By incorporating ESG principles into academic frameworks, students are equipped with technical knowledge and cultivate a profound comprehension of worldwide viewpoints and conscientious conduct. This social aspect is consistent with more extensive societal objectives, as defined in Saudi Vision 2030, which underscores the critical role of education in propelling progress within society.

Policymakers may consider these findings as they devise approaches to synchronise educational establishments with wider sociocultural and environmental goals, thereby fostering a future characterised by sustainability and social consciousness.

6.2.1 Future Avenues for Research

An Empirical Evaluation of the Impact of Sustainability

An empirical investigation could be done to evaluate the sustainability impact of infrastructure upgrades in higher education institutions through rigorous studies. This study could encompass the monitoring and measuring of alterations in energy usage, carbon emissions, waste mitigation and additional sustainability metrics after enhancements are made to the infrastructure. Surveys, energy audits and sustainability reporting data would be considered significant sources of empirical evidence.

The Impact of Education Quality on Student Outcomes

A empirical study could be conducted to investigate the impact of infrastructure upgrades on the quality of education and student outcomes. It could use quantifiable evaluations, such as standardised tests, graduation rates and student satisfaction surveys to gauge the influence of technology-integrated educational settings on academic achievement and comprehensive learning encounters.

Qualitative research could offer more profound insights into these changes' impact on teaching and learning processes (Baglibel et al., 2018). In innovation and research productivity, metrics play a crucial role in assessing and evaluating the effectiveness and efficiency of these processes. The study could use quantitative measures to assess the tangible effects of innovation and research productivity from implementing infrastructure changes. This may entail the examination of several factors, such as the extent of multidisciplinary collaborations, the amount of research funds acquired, the number of patent applications, and the number of academic publications.

Comparative studies could be used to evaluate whether institutions with superior IT infrastructure demonstrate elevated innovation and research productivity levels.

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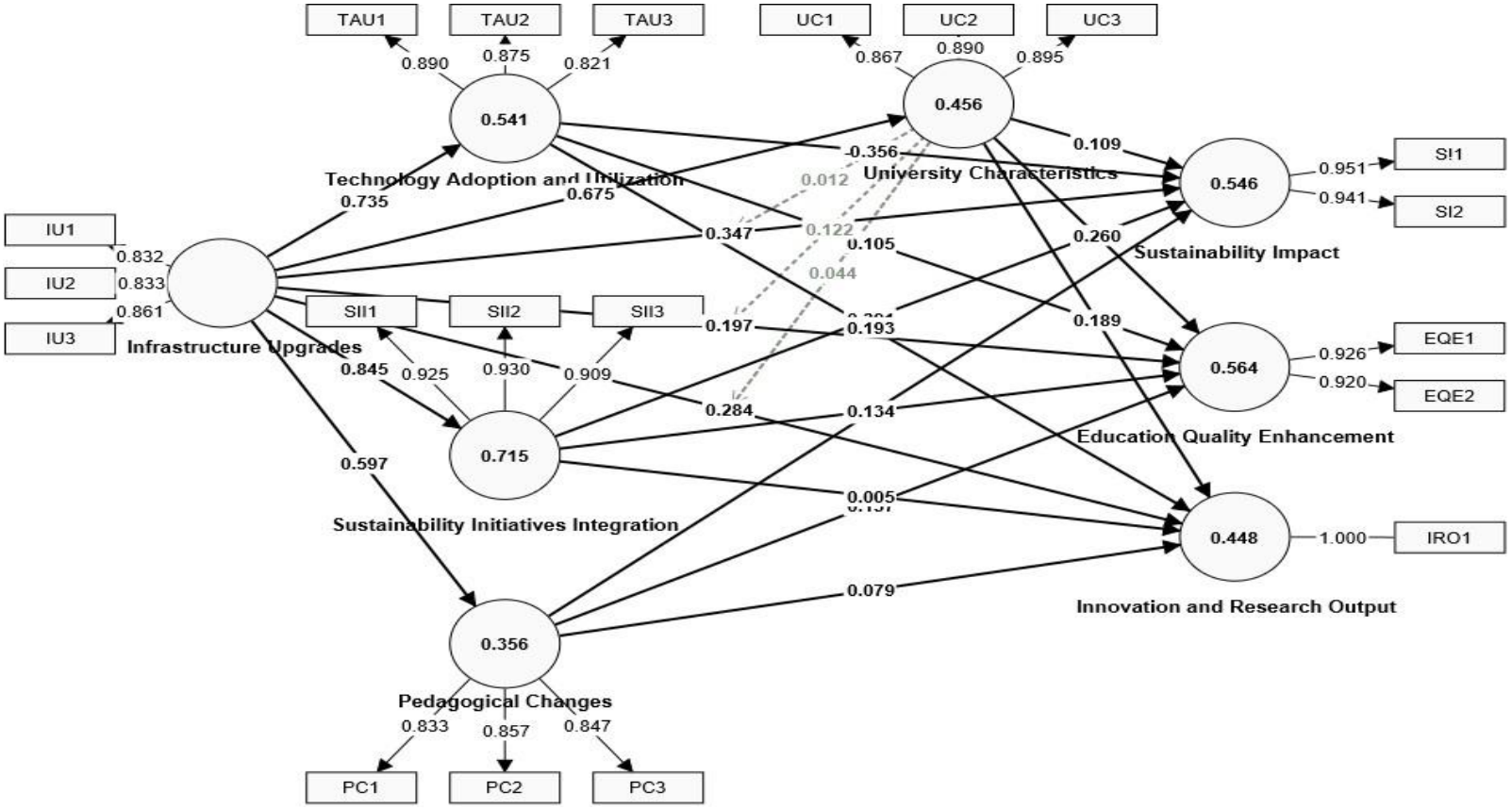
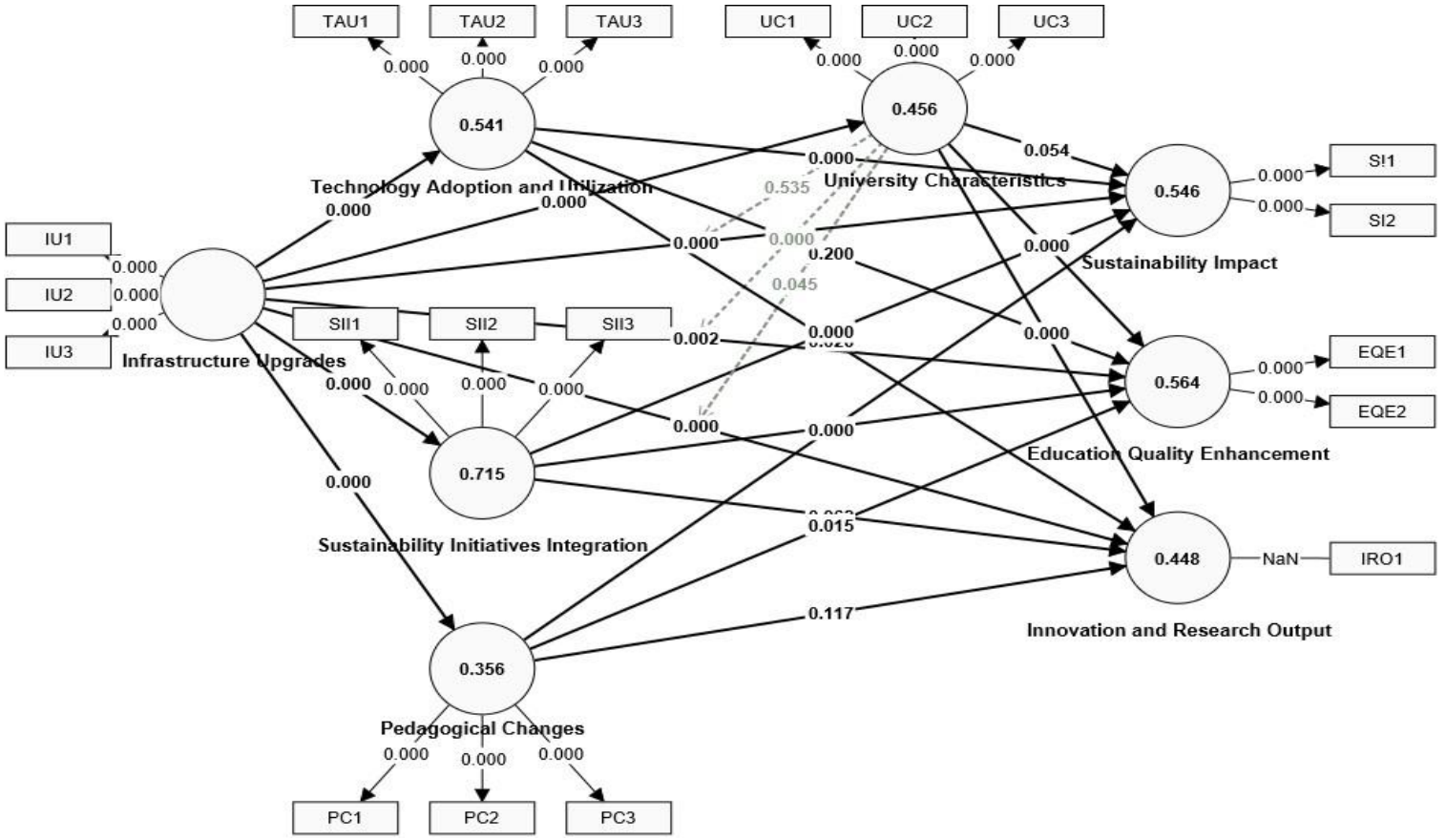
Appendix 1

Measurement Model



Appendix 2

Structural Model



Appendix 3

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Infrastructure Upgrades -> Education Quality Enhancement	0.646	0.646	0.025	26.308	0.000
Infrastructure Upgrades -> Innovation and Research Output	0.605	0.606	0.032	18.915	0.000
Infrastructure Upgrades -> Pedagogical Changes	0.597	0.598	0.035	16.922	0.000
Infrastructure Upgrades -> Sustainability Impact	0.681	0.682	0.023	29.555	0.000
Infrastructure Upgrades -> Sustainability Initiatives Integration	0.845	0.846	0.014	62.151	0.000
Infrastructure Upgrades -> Technology Adoption and Utilisation	0.735	0.736	0.026	27.901	0.000
Infrastructure Upgrades -> University Characteristics	0.675	0.677	0.029	22.975	0.000
Pedagogical Changes -> Education Quality Enhancement	0.137	0.139	0.056	2.431	0.015
Pedagogical Changes -> Innovation and Research Output	0.079	0.079	0.05	1.566	0.117
Pedagogical Changes -> Sustainability Impact	0.321	0.322	0.051	6.321	0.000
Sustainability Initiatives Integration -> Education Quality Enhancement	0.134	0.136	0.092	1.460	0.144
Sustainability Initiatives Integration -> Innovation and Research Output	0.005	0.006	0.112	0.048	0.962
Sustainability Initiatives Integration -> Sustainability Impact	0.391	0.387	0.099	3.947	0.000
Technology Adoption and Utilisation -> Education Quality Enhancement	0.105	0.105	0.082	1.281	0.200
Technology Adoption and Utilisation -> Innovation and Research Output	0.193	0.191	0.087	2.230	0.026
Technology Adoption and Utilisation -> Sustainability Impact	-0.356	-0.354	0.087	4.114	0.000
University Characteristics -> Education Quality Enhancement	0.260	0.261	0.054	4.846	0.000
University Characteristics -> Innovation and Research Output	0.189	0.191	0.052	3.610	0.000
University Characteristics -> Sustainability Impact	0.109	0.112	0.057	1.929	0.054
University Characteristics x Infrastructure Upgrades -> Education Quality Enhancement	0.122	0.121	0.020	5.946	0.000
University Characteristics x Infrastructure Upgrades -> Innovation and Research Output	0.044	0.044	0.022	2.002	0.045
University Characteristics x Infrastructure Upgrades -> Sustainability Impact	0.012	0.013	0.020	0.621	0.535

Appendix 4

Questionnaire

Dear Participants,

We are surveying "Integrating IT and Sustainability in Higher Education Infrastructure: Impacts on Quality, Innovation, and Research." Designed to gather insights from participants, it focuses on various aspects such as infrastructure upgrades, technology adoption, sustainability integration, and more. Our research aims to delve into the dynamic relationships between Information Technology (IT) and sustainability within the framework of higher education infrastructure. Participants, whether students or faculty members are encouraged to share their perceptions and experiences, contributing valuable information to understand the intricate connections between information technology and sustainability in higher education. The questionnaire emphasizes confidentiality, assuring participants that their responses are secure and anonymous and will be used exclusively for research purposes.

Name:
Age:
Occupation:
Gender:
Student:
Faculty:
Program Enrolled in:
Semester:
Name of University:
Technological Exposure:

How much has your university invested in upgrading its IT infrastructure in the past year?

How satisfied are you with the current state of IT infrastructure at your university?

In your opinion, how has the recent infrastructure upgrade positively affected your academic experience?

How frequently do you use technology tools and applications for your academic activities?

To what extent has integrating technology enhanced your ability to collaborate with peers on academic projects?

In your opinion, how has technology adoption positively impacted the overall learning environment at your university?

Are you aware of any sustainability initiatives integrated into the academic curriculum at your university?

How do you perceive the effectiveness of these sustainability initiatives in promoting environmental awareness among students?

In your opinion, what additional sustainability measures could be integrated into the university's practices?

Have you noticed any recent pedagogical changes in how courses are delivered at your university?

How do you feel these pedagogical changes have influenced your learning experience?

What specific pedagogical approaches have contributed most to improving the quality of education at your university?

In your view, how has the university's focus on sustainability positively impacted the local community?

To what extent do you believe the sustainability efforts at your university contribute to your commitment to environmental responsibility?

How satisfied are you with the overall quality of education your university provides?
In your opinion, what specific aspects of the education system at your university could be improved to enhance overall quality?
To what extent do you think the university encourages and supports innovation among students and faculty?