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Editorial

Navigating Transformational Landscapes: Challenges and Opportunities in Technology, Consumer Behavior, and Entrepreneurship

As we launch the inaugural issue of Volume 2 of *LABSREVIEW*, we reaffirm our commitment to serving as a dynamic scholarly platform that interrogates the critical intersections of technology, consumer behavior, organizational dynamics, and entrepreneurship across diverse global contexts.

This issue captures the evolving and multifaceted relationship between technological advancement and its organizational and societal implications. We begin with a thought-provoking investigation into technological insecurity and its effects on job satisfaction and organizational commitment among university administrative personnel. This study highlights how, despite the promise of efficiency, rapid technological change can engender uncertainty and disrupt employees' sense of stability and alignment with institutional values.

Building on this theme, the second article examines the adoption of Industry 4.0 technologies by Micro, Small, and Medium Enterprises (MSMEs) in the Caribbean. The authors illuminate smaller firms' challenges and adaptive strategies through rigorous multiple case analyses, offering valuable insights into regional innovation and resilience in the face of digital transformation.

Shifting focus to consumer behavior, our third article explores post-pandemic travel preferences in South Africa, specifically through the lenses of xenocentrism and ethnocentrism. This timely study provides a nuanced understanding of consumer decision-making post-crisis and offers strategic implications for tourism marketers navigating evolving cultural and psychological landscapes.

The fourth article investigates the impact of university and social contexts on entrepreneurial intentions in Latin America. The findings underscore the significance of educational ecosystems and social environments in cultivating entrepreneurial mindsets, presenting important policy and curriculum development considerations to foster innovation and enterprise.

This issue concludes with an analysis of smart water management systems implemented at a Philippine state university. This article articulates the operational challenges and strategic opportunities associated with sustainable resource management in educational institutions, reinforcing our ongoing commitment to sustainability and innovation in public infrastructure.

These contributions reflect a global, interdisciplinary approach to understanding contemporary organizational and societal challenges. We sincerely appreciate the authors, peer reviewers, and editorial team whose expertise and dedication have made this issue possible.

We encourage our readers to engage thoughtfully in these discussions and to contribute to the ongoing dialogue shaping the future of business, technology, and sustainability.
Warm regards,

Most respectfully,

Dr. Luis Camacho
Editor-in-Chief, *LABSREVIEW*
SUNY Empire State University

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Article

La Inseguridad Tecnológica y su incidencia en la satisfacción laboral y compromiso organizativo del personal administrativo universitario

Sergio Araya-Guzmán [1,*], ***Marcela Guiñez-Pérez*** [2] **and** ***Yarisel Bueno-Broterson*** [3]

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[1] *Universidad del Bío-Bío, Chile*; saraya@ubiobio.cl
[2] *Universidad del Bío-Bío, Chile*; mgunez@ubiobio.cl
[3] *Universidad del Bío-Bío, Chile;* yarisel.bueno2201@alumnos.ubiobio.cl
* Correspondence: saraya@ubiobio.cl

Resumen: Este trabajo presenta resultados obtenidos de un estudio cuyo objetivo es establecer si la inseguridad tecnológica, como creador de tecnoestrés, presenta una incidencia en la satisfacción laboral y compromiso organizativo de usuarios de TIC, en el contexto del personal administrativo universitario. Para tal efecto se han aplicado encuestas a tales actores, usuarios de estas tecnologías. Los resultados del análisis de ecuaciones estructurales indican que existe un nivel de predicción del efecto de la sensación de amenaza de perder el trabajo debido a las nuevas tecnologías sobre el compromiso organizativo y que la satisfacción laboral influye en el compromiso organizativo del personal administrativo universitario.

Palabras clave: Inseguridad Tecnológica, Satisfacción Laboral, Compromiso Organizativo.

1. Introducción

Las Tecnologías de Información y Comunicación (TIC) son ampliamente utilizadas en distintas organizaciones y en todo tipo de funciones que se desarrollan, favoreciendo la agilidad y amigabilidad en la ejecución de las tareas, así como los niveles de productividad y rendimiento alcanzados, generando incluso ventajas competitivas, constituyendo un aspecto positivo del uso de estas tecnologías.

Sin embargo, el uso de las TIC también ha ocasionado ciertos aspectos considerados negativos para las personas (y por lo tanto para las organizaciones), afectándoles psicológicamente, en su comportamiento, mostrando síntomas de estrés por su utilización, lo que se ha denominado como tecnoestrés (Ragu-Nathan et al., 2008; Tarafdar et al., 2010). Entre los creadores de tecnoestrés se encuentra la inseguridad tecnológica, relacionada con sensaciones de amenaza de perder el trabajo debido a las nuevas tecnologías.

En este contexto, este trabajo entrega algunos resultados obtenidos en un proyecto que aborda el tecnoestrés y su efecto sobre el comportamiento organizativo, presentándose, específicamente, el efecto de uno de los creadores de tecnoestrés, la inseguridad tecnológica, sobre la satisfacción laboral y compromiso organizativo de usuarios finales de TIC, en un tipo particular de organizaciones, las instituciones universitarias, considerándose como unidad de análisis el personal administrativo de estas entidades.

2. Revisión de literatura

2.1. Inseguridad Tecnológica

La inseguridad tecnológica es uno de los creadores de tecnoestrés señalados por Tarafdar, Tu y Ragu-Nathan (2010), y se refiere a las situaciones en las que los usuarios se sienten amenazados por perder sus trabajos, ya sea por la automatización resultante de las nuevas tecnologías o porque otras personas tienen una mejor comprensión y manejo de ellas.

El tecnoestrés se entiende como un estado fisio-psicológico no saludable, relacionado con el uso de las tecnologías de la información y la comunicación o la percepción de amenaza en su uso desmedido, que se produce cuando se registra un desajuste entre las demandas que plantea el uso de cualquier tecnología y los recursos disponibles para gestionarlas (Ragu-Nathan et al., 2010). Surge como consecuencia de los intentos y luchas de una persona por lidiar con las TIC, las que están en constante cambio y evolución, al igual que los cambios en las necesidades cognitivas y sociales relacionadas con su utilización (Nimrod, 2017). Como concepto, el tecnoestrés fue planteado por el psiquiatra norteamericano Craig Brod, el año 1984, quien lo define como "una enfermedad de adopción causada por la falta de habilidad para tratar con las nuevas tecnologías informáticas de manera saludable" (Brod, 1984).

2.2. Satisfacción laboral y compromiso organizativo

La satisfacción laboral es entendida como el conjunto de sentimientos o actitudes favorables o desfavorables de los trabajadores hacia su puesto de trabajo o actividad laboral (Davis y Newstrom, 1987), es la actitud o conjunto de actitudes desarrolladas por las personas hacia su situación de trabajo (Bravo, Peiró y Rodríguez, 1996), la satisfacción en el trabajo es una actitud afectiva, una sensación de relativo gusto o disgusto hacia algo (Alcas et al., 2019).

El compromiso organizativo, según Allen, Meyer y Smith (1993), es "el estado psicológico que caracteriza las relaciones entre los empleados y la organización y tiene implicancias en las decisiones de continuar o dejar de ser miembro de la organización", es una respuesta actitudinal tras la evaluación de la situación laboral, lo que conlleva a que el individuo se adhiera (comprometa) o no a la organización (Mowday, Porter y Steers, 1982), se refiere a la lealtad o apego de un individuo hacia la organización que lo emplea (Bozeman y Perrewé, 2001), puede entenderse, por tanto, como el grado en que un empleado se identifica con la organización y desea seguir participando de ella (Davis y Newstrom, 2001, Robbins y Coulter, 2010).

2.3. Formulación de Hipótesis

La percepción que los usuarios pueden presentar de los sistemas y tecnologías de información podría afectar la percepción que tienen sobre aspectos relacionados con su trabajo y por lo tanto con características de la organización (Araya et al., 2021), afectando su actitud y comportamiento, los que se relacionan directamente con la satisfacción y compromiso organizativo de las personas (Sánchez et al., 2013). En este sentido, la inseguridad tecnológica, como creador de tecnoestrés, puede producir un efecto negativo en las personas, como sentirse amenazados por perder el trabajo por los aportes de las nuevas tecnologías o por que los demás comprenden y manejan mejor la tecnología, provocando una disminución de su satisfacción laboral, lo que puede ocasionar un menor compromiso de continuidad en la organización (Ragu-Nathan et al., 2008).

Estos planteamientos llevan a suponer que puede existir una relación entre la inseguridad tecnológica (creador de tecnoestrés) con el comportamiento de los individuos, incidiendo en su satisfacción laboral y compromiso con la organización, lo que permite formular las siguientes hipótesis de investigación, en el contexto de estudio, el personal administrativo Universitario:

H1: La inseguridad tecnológica incide negativamente en la satisfacción laboral de los usuarios de TIC, del personal administrativo de universidades.
H2: La inseguridad tecnológica incide negativamente en el compromiso organizativo de los usuarios de TIC, del personal administrativo de universidades.

La satisfacción laboral es importante debido a su supuesta relación con la productividad de la persona, lo que se traduce como un mejor desempeño laboral y en consecuencia conlleva a un mayor cuidado del empleador, lo cual genera un mayor compromiso con la organización (Cernas, Mercado y León, 2018), lo que es reforzado por Arce y Rojas (2020) quienes indican que un empleado satisfecho genera un aumento en su compromiso con la organización. El planteamiento anterior origina la siguiente hipótesis:

H3: La satisfacción laboral incide positivamente en el compromiso organizativo, del personal administrativo de universidades.

3. Materiales y métodos

Este estudio es de carácter exploratorio, donde la validación de las hipótesis propuestas considera un estudio empírico efectuado en universidades de la región del Biobío de Chile, aplicando, por medio de correo electrónico, instrumentos de medición a personal administrativo de estas instituciones que utilizan TIC (plataformas digitales) para ejecutar todas o algunas de sus funciones, con por lo menos un año de antigüedad en la organización. Los instrumentos de medición utilizados corresponden a instrumentos ya definidos y utilizados en estudios anteriores (Araya-Guzmán et al, 2023; Guiñez-Pérez et al., 2022), utilizando una escala Likert de cinco puntos, donde uno es el valor más bajo y cinco el valor más alto. El análisis estadístico de los datos contempla la aplicación de modelo de ecuaciones estructurales y la utilización del software SmartPLS (4.0).

4. Resultados

Este trabajo presenta los resultados obtenidos para 287 casos de encuestas válidas obtenidas, correspondiendo a un 69,3% de personas de género femenino, 30% masculino y 0,6 de otro género; un 11,3% menor que 30 años y un 68% entre 30 y 49 años; el 34% entre 11 y 20 años de experiencia laboral y un 28,6% más de 20 años de experiencia; el 50% con contrato profesional y el 48,6% con contrato técnico-administrativo; el 50% con formación universitaria y el 25,3% con formación técnico-profesional.

El modelo de investigación contempla tres constructos de primer orden: Inseguridad Tecnológica, Satisfacción Laboral y Compromiso Organizativo. Los datos obtenidos, una vez finalizado el proceso de aplicación de PLS se presentan en las tablas siguientes.

La evaluación del modelo de medida (Hair et al., 2017) contempla la medición de la validez y fiabilidad del modelo de orden superior, encontrándose que las cargas de los indicadores cumplen con la fiabilidad individual del ítem (valor mínimo exigido 0,707). Los índices de fiabilidad compuesta (ρc) y de varianza media extraída (AVE) superan los valores generalmente aceptados (mínimo 0,7 para fiabilidad compuesta y AVE mayor que 0,5), cumpliéndose en consecuencia la fiabilidad de los constructos y la validez convergente, respectivamente. Los resultados obtenidos en esta medición se presentan en la tabla 1. La tabla 2 presenta el análisis de validez discriminante utilizando el criterio Heterotrait-Monotrait (HTMT), cumpliéndose satisfactoriamente esta evaluación (umbral de HTMT de 0.85). Luego, los resultados obtenidos muestran que se cumple la evaluación del modelo de medida en forma satisfactoria

Tabla 1. Cargas, Fiabilidad Compuesta, Alfa de Cronbach y AVE

Constructo/Ítem	Cargas	Fiabilidad Compuesta (Ro_c)	Alfa de Cronbach	Varianza Extraída Media (AVE)
Inseguridad Tecnológica (INST)		0.902	0.902	0.697
INST1	0,806			
INST2	0,851			
INST3	0,827			
INST5	0,855			
Satisfacción Laboral (SL)		0,948	0,918	0,859
SL1	0,942			
SL2	0,929			
SL3	0,908			
Compromiso Organizativo (CO)		0,938	0,902	0,836
CO1	0,927			
CO2	0,936			
CO4	0,878			

Tabla 2. Validez Discriminante (Criterio HTMT)

Constructo	CO	INST	SL
Compromiso Organizativo (CO)			
Inseguridad Tecnológica (INST)	0,082		
Satisfacción Laboral (SL)	0,742	0,195	

La evaluación del modelo estructural (Hair et al., 2017) contempla el análisis de la colinealidad, coeficientes de trayectoria del modelo estructural (coeficientes path) y varianza explicada R^2. La colinealidad surge cuando dos constructos están altamente correlacionados, por lo que la colinealidad examina cada conjunto de constructos predictores, el factor de la inflación de la varianza (VIF) debe de ser mayor de 0.2 y menor o igual que 5.0. Los coeficientes de trayectoria muestran las relaciones de las hipótesis del modelo de investigación (magnitud entre +1 a -1), entre mayor sea el valor mayor relación (predicción) entre constructos; si el resultado de un valor path es contrario al signo establecido en la hipótesis, ésta no será soportada.

La varianza explicada (R2) (Hair et al., 2017) representa una medida de valor predictivo, indica la capacidad de predicción de las variables dependientes (indica la cantidad de varianza de un constructo que es explicada por las variables predictoras del constructo endógeno, con valores que oscilan entre 0 y 1), donde, mientras más alto sea el valor de R2, más capacidad predictiva se presenta; Falk y Miller (1992) consideran que R2 debe tener un valor mínimo de 0.10; Chin (1998) considera 0.67, 0.33 y 0.10 (sustancial, moderado y débil); mientras que Hair et al. (2017) recomiendan 0.75, 0.50, 0.25 (sustancial, moderado y débil).

El nivel de significancia (Hair et al., 2017) se determina a partir del valor de la t Student que deriva del proceso de re muestreo o bootstrapping, que es una técnica no paramétrica.

El contraste de las hipótesis debe considerar los resultados obtenidos de la evaluación del modelo estructural, contemplándose la varianza explicada (R2), la relación entre los constructos establecida en las hipótesis debe presentar un coeficiente path (β) del mismo signo que fue formulado, y los parámetros deben ser estadísticamente significativos.

La tabla 3 muestra los valores VIF obtenidos, la tabla 4 los valores de R2, mientras que la tabla 5 presenta los valores de coeficientes path, indicadores y significancia estadística correspondientes. La evaluación del modelo estructural contempla (Hair et al., 2023), el análisis de la colinealidad, coeficientes de trayectoria del modelo estructural (coeficientes path) y varianza explicada R2; la colinealidad surge cuando dos constructos están altamente correlacionados, por lo que la colinealidad examina cada conjunto de constructos predictores, exigiéndose que el factor de la inflación de la varianza (VIF) debe de ser mayor de 0,2 y menor o igual que 5,0, lo que se cumple ampliamente.

El contraste de las hipótesis debe considerar los resultados obtenidos de la evaluación del modelo structural (Hair et al., 2023). La significancia estadística asociada a los coeficientes path se establece con el procedimiento bootstrapping (5.000 muestras) (tabla 3).

Tabla 3. Colinealidad (VIF)

Constructo	CO	INST	SL
Compromiso Organizativo (CO)			
Inseguridad Tecnológica (INST)	1,039		1,000
Satisfacción Laboral (SL)	1.039		

Tabla 4. Varianza Explicada (R^2)

Constructo	R2
Satisfacción Laboral (SL)	0,038
Compromiso Organizativo (CO)	0,499

Tabla 5. Coeficientes Path y Significancia Estadística

Relación	Coeficiente Path(β)	T-estadísticos/ p valor	Significancia Estadística
Inseguridad Tecnológica → Satisfacción Laboral	-0,195	2,652/0,008	**
Inseguridad Tecnológica → Compromiso Organizativo	-0,181	4,004/0,000	***
Satisfacción Laboral → Compromiso Organizativo	0,719	14,244/0,000	***
Para n=5000 submuestras: *p<0.05; ** p<0.01; *** p<0.001 (basado en una distribución t(499) de Student de una cola) t(0.05; 499)=1.64791345; t(0.01; 499)=2.333843952; t(0.001; 499)=3.106644601			

La figura 1 muestra esquemáticamente el resultado de la evaluación del modelo estructural.

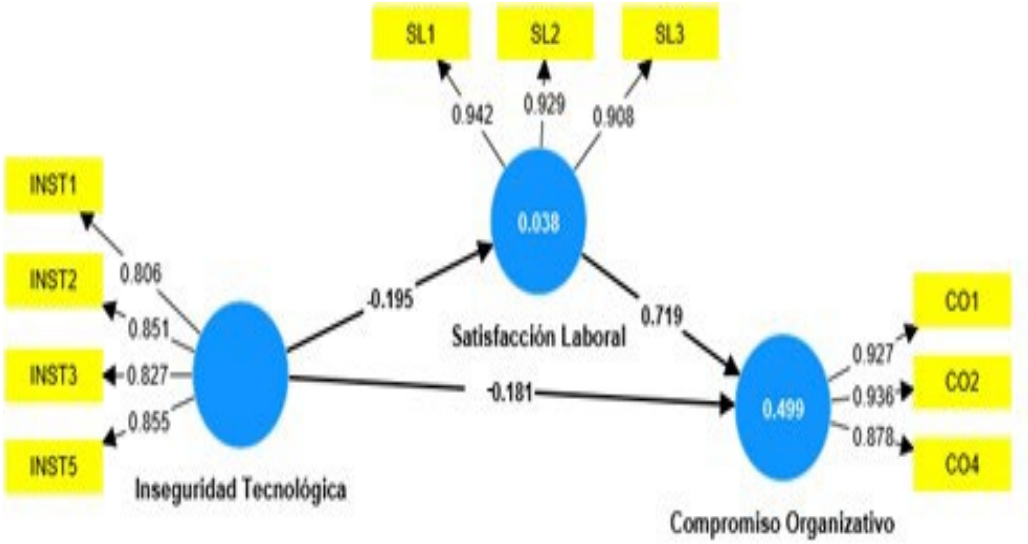

Figura 1. Modelo Estructural

Los resultados indican que, en el personal administrativo universitario, la inseguridad tecnológica incide negativamente sobre la satisfacción laboral y sobre el compromiso organizativo, y que la satisfacción laboral también influye positivamente sobre el compromiso organizativo. Si bien los valores obtenidos presentan significancia estadística, el valor de la varianza explicada de la satisfacción laboral es inferior a 0,1 (Chin, 1998), lo que se arroja que se sustentan las hipótesis H2 y H3, no obstante, consideramos importante el hecho que la inseguridad tecnológica afecte a la satisfacción laboral, aunque, según los resultados obtenidos, el nivel de predicción no es suficiente para soportar la hipótesis formulada.

La inseguridad tecnológica, es decir, sentir una amenaza constante para la seguridad del trabajo debido a las nuevas tecnologías, el hecho de tener que actualizar constantemente las habilidades personales para evitar ser reemplazado, el sentirse amenazado por los compañeros de trabajo con nuevas habilidades tecnológicas, y sentir que hay menos intercambio de conocimientos entre los compañeros de trabajo por temor a ser reemplazados, son factores que afectan al compromiso organizativo y a la satisfacción laboral (aunque para ésta no presenta un valor predictivo significativo).

La satisfacción laboral, referida al gusto que se experimenta por lo que se hace en el trabajo, el orgullo de hacer el trabajo, y sentir que el trabajo es agradable, son aspectos que inciden en el compromiso organizativo (querer continuar trabajando en la organización, disfrutar hablar de la organización con personas ajenas a ella, sentir que los problemas de la organización son propios, y sentir que la organización tiene mucho significado personal).

Con respecto a la colinealidad del modelo, no existe colinealidad entre constructos ya que los valores del factor de inflación de la varianza están dentro del rango permitido (VIF>0.2 y VIF<=5.0). Los resultados obtenidos indican que la variación de la satisfacción laboral es explicada en un 3,8% por la variación de la inseguridad tecnológica (pero no presenta un valor predictivo relevante), y que la variación del compromiso organizativo es explicada en un 49,9% por la variación de la inseguridad tecnológica y de la satisfacción laboral.

5. Conclusiones

Este estudio puede significar un aporte práctico para que los directivos de instituciones universitarias presten atención a la actitud que muestre el personal administrativo frente al uso de las tecnologías para el desarrollo de sus actividades laborales, de manera de identificar posibles inconvenientes, y definan políticas y mecanismos que promuevan una mejora en esta situación (como charlas y capacitaciones permanentes, promover el intercambio de conocimientos y trabajo colaborativo, mantener un buen servicio de soporte a usuarios), lo que facilitaría el logro de una mejor actitud de estos colaboradores hacia la utilización de estas herramientas, disminuyendo su sensación de inseguridad tecnológica, apoyando con ello el alcance de mejores niveles de satisfacción laboral y de compromiso organizativo, lo que sin duda repercutirá en el rendimiento y productividad de la organización.

Los datos obtenidos han sido recopilados en instituciones universitarias con sede en las regiones de Ñuble y Biobío, lo que constituye la principal limitación, lo que, a su vez, motiva el desarrollo de futuras investigaciones, abarcando más zonas geográficas, lo que permitiría realizar un análisis más amplio en el contexto de estas

organizaciones, siendo posible, incluso, llevar a cabo un análisis comparativo entre instituciones de distintas zonas geográficas.

Sumado a lo anterior, este estudio no ha efectuado un análisis considerando variables de control, como el género, la edad, la experiencia, entre otras, lo que, de igual forma, puede dar origen a nuevos análisis que permitan enriquecer los resultados hasta ahora obtenidos. Más aún, el estudio no ha contemplado como elemento de control el tipo de institución (estatal y pública, privada con aporte del estado, privada), lo que puede motivar nuevos estudios futuros.

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Case study

Adoption of 4.0 technologies in MSMEs in the Caribbean: A multiple cases study

Karen L. Orengo Serra[1]

[1] Universidad de Puerto Rico, Puerto Rico; karenl.orengo@upr.edu

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Abstract: By employing the qualitative methodology of multiple case studies, the adoption of 4.0 technologies in MSMEs in Puerto Rico is explored in terms of the drivers, benefits, problems, and challenges of the incorporation processes. The findings reflect that MSMEs belong mostly to the regulated sector and agree that adopting technologies allows them interoperability, data analysis, projections, efficiency, and effectiveness in real-time and close and frequent linkage with customers. Study participants highlight their dependence on the power energy system and its instability as the most significant obstacles, in addition to the lack of capital. The resilient infrastructure component (energy and technology) evidences the need for future research on the subject from a geospatial approach, which imparts originality to this study and determines its importance in developing public policies and resilient business models.

Keywords: 4.0 technologies, MSMEs, digitalization, regulated industry.

1. Introduction

Digital technologies can generate opportunities for improvement in all areas of companies' business: in production processes, in the increase of the portfolio of contact networks, and also in the extension of their information capacity in an almost infinite way, both towards new cognitive areas, as well as towards areas of specialization already consolidated in the company and, in cases of disruptive events, in their ability to reconfigure their resources and thus respond more quickly to crises (Ascúa et al., 2021; ECLAC, 2022). In Canada, for example, these technologies adopted by micro, small, and medium-sized enterprises (MSMEs)have implied higher productivity, lower costs, and better product quality (Bédard-Maltais, 2018). A study conducted in the central region of Malaysia on small and medium-sized enterprises (SMEs) found that digital transformation has relevant implications for business performance (Nor al., 2021). However, in developing countries, many SMEs are experiencing delays in introducing smart manufacturing and the digitalization of factories due to a lack of knowledge and communication problems, which implies a lag (Atieh et al., 2023).

Empirical data in Latin America and the Caribbean (LAC) indicate that the digitalization process has been uneven between large and MSMEs (Cuéllar, 2020). The most critical elements that explain this disparity are the lack of knowledge about these technologies, the dearth of infrastructure, necessary internal connectivity, skills, access to qualified human resources, organizational culture, financing, and education system (Ascúa, 2021).

In the case of small island economies, additional challenges are added to these elements, namely, vulnerabilities associated with the size of the territory, scarcity of resources, and exposure to disruptions related to climatic events, which in turn impact economies and their energy, water, transportation, technological and supply chain infrastructures. Addressing this issue in island economies makes conducting studies such as this one essential. This study proposes an exploratory approach to the technologies that make up Industry 4.0 based on multiple case studies of companies operating in Puerto Rico, essentially MSMEs from various commercial and/or

industrial sectors. The aim is to identify those technologies that are most used or essential for the flow of daily operations, and that impact the parameters that define efficiency and effectiveness. The scope of adopting 4.0 technologies in Puerto Rico companies is explored regarding the incorporation processes' motivations, benefits, problems, challenges, and results. In what instance were the new 4.0 technologies implemented? Are they in implementation, or are they projected to be implemented? What were the motivations and benefits of the introduction of 4.0 technologies? What were the relevant obstacles to the incorporation of 4.0 technologies? What were those relevant obstacles to incorporating 4.0 technologies from the perspective of the disruptions to which the country is exposed due to its geomorphology? What modes of financing and types of non-financial aid did you report? These are the questions that guide this study.

The existing literature on adopting 4.0 technologies in Latin America is mainly limited to large companies, especially in the technology and service sectors, with scarce analyses on MSMEs (Carmona et al., 2020). This research is original in that it is one of the few studies to explore 4.0 technologies in MSMEs in island territories, which present a complicated environment due to their geomorphology, contributing to public policy, academia, and the private sector regarding the adoption of these technologies, of the Fourth Industrial Revolution (4IR). The following section outlines a theoretical framework focused on MSMEs and 4.0 technologies. Then, the method used for the study is presented, followed by the results and conclusions.

2. Literature review

After the COVID-19 pandemic, the shift to exploration and use of 4.0 technologies by companies in Latin America favored the continuity of their operations and organizational restructuring. This highlighted the importance of these technologies in business competitiveness. Despite this shift towards companies' adoption of technologies, the region's ability to compete with other nations remains limited. According to the 2020 Digital Competitiveness Index, prepared by the Institute for Management Development, among the 63 countries considered by the study, Chile was the economy with the best score in digital competitiveness, with approximately 61.5 points out of 100, ranking 41st. It is followed by Brazil in 51st place, with 52.1 points. The third and fourth places are occupied by Mexico and Peru, with 51.5 and 50.1 points, respectively, occupying the 54th and 55th positions in that range (IMD, 2020). This does not mean that the region has not experienced progress in digitalization but that the impact on performance in digital transformation has been moderate. While some companies have managed to capture much of the benefits of digital technologies, there is a long tail of companies lagging in digital matters, mainly composed of MSMEs and businesses in traditional and vulnerable activities, all of which are generally associated with lower levels of productivity and greater informality (ECLAC, 2022). Financial services and the information and communications technology (ICT) sector are the activities with the highest level of digitalization in the region and worldwide, while agriculture, real estate services, and education are lagging behind sectors.

Within the manufacturing industry, there is substantial heterogeneity between countries. In Argentina, there are high levels of digitalization in the biopharmaceutical and automotive sectors, while in the agricultural machinery, food, and textile sectors, lower levels of digitalization predominate. In Colombia and Brazil, the levels of digitization in services are high, medium in logistics services, and low in agribusiness. Colombia and Brazil reflect a moderate and low level of manufacturing (ECLAC, 2022). In the case of Brazil, companies in the high-tech sector still reflect that digital adoption has advanced but is still in an incipient stage (Urraca-Ruiz et al., 2023).

It is observed that there is a lag in terms of the adoption of 4.0 technologies in companies in Latin America. However, a study reveals that in Colombia, Ecuador, Mexico, Panama, and Peru, there is a positive attitude on the part of companies towards the adoption of these technologies due to the perceived ease and usefulness as well as the attitude towards 4IR technologies (Cordero et al., 2023). In Brazil, a study of companies in the high-tech sector shows that current adoption, size, belonging to digitally intensive industries, exporter, and training the workforce have a significant positive effect on the adoption of 4.0 technologies. (Urraca-Ruiz et al., 2023). On the contrary, the size of the company, access to contact networks, capital, skilled and professional workforce, as well as infrastructure are elements that inhibit the adoption and implementation of 4.0 technologies in Latin American companies (Ascúa, 2021; Carmona et al., 2020; ECLAC, 2022).

Of all the elements, the one linked to vocational training is an imminent brake on the acceleration towards adopting 4.0 technologies. Although most countries in the region have increased coverage of and access to basic, secondary, and technical-vocational education, there are no positive results in terms of quality. The education system does not have connectivity, devices, and teaching skills to develop logical thinking, problem-solving skills, and socio-emotional and collaborative work skills, essential components for assimilating and exploiting new technologies (ECLAC, 2022). The region's PISA scores in mathematics, reading, and science are below the average for the Organization for Economic Cooperation and Development (OECD) member countries. Less than 20 percent of students aged 24 to 35 have completed tertiary or university studies in Argentina and Brazil, compared with almost 50 percent in OECD member countries (ECLAC, 2022).

Few students are inclined toward technical careers or science, technology, engineering, and mathematics, which are the most in-demand by companies whose growth potential is based on innovation and new technologies (ECLAC, 2022). In other elements that are essential for the adoption of digital technologies, the lack of knowledge and proper training slows down and hinders the development of the digital ecosystem required to develop networks, attract capital investments, and prioritize the infrastructures that are needed (Ascúa, 2021; ECLAC, 2022).

3. Material and methods

This study employed a multiple case study. The instrument for data collection is a guide of structured, open, and closed questions, designed from the methodological guide of Carmona et al. (2020) in the context of the Euromipyme project led by the Economic Commission for Latin America and the Caribbean (ECLAC) to promote the adoption of new digital technologies in Latin American MSMEs.

The instrument is configured in three blocks. Block 1 collected data on the incorporation and use of new digital technologies. Block 2 included questions about the general description of the projects, investments, or services contracted in new digital technologies. Block 3 grouped questions aligned with projects, investments, or contracted services. This block focuses on questions about the motivations, problems, obstacles, and benefits of adopting 4.0 technologies with an emphasis on internal and external elements of the company. It is incorporated into the component of resilience to disruptive events. This component allowed us to observe whether or not the experiences of companies influenced the adoption of these technologies before disruptions associated with geomorphology and infrastructure.

Motivations, benefits, and obstacles were collected on a scale of 1 to 4, with 1 being the main reasons, 2 being Relevant but not the main reason, 3 being little or not relevant, and 4 not applicable. Likewise, the companies were asked to elaborate on the reasons for the categorizations and responses. Built-in reasons include improving the efficiency of a function or process, cost savings, staff replacement, quality, customer relations, supplier relationships, new product development or associated new services, and new business model development. Internal obstacles to the company include Lack of knowledge about the technology, Lack of interest/other more urgent projects require attention, Lack of interest/negative benefit-cost evaluation, Lack of qualified human resources for implementation, Lack of financial resources for investment, Lack of necessary infrastructure and internal connectivity, others to be specified. For External Obstacles to the company, the selection includes Immature technology, Lack of suppliers of technological products or services, Lack of financing supply or financing conditions are not adequate, Lack of availability of qualified personnel in the labor market, Insufficient training and training system for new requirements, Weak or insufficient information and communications infrastructure, Macroeconomic context, Instability of the economy.

Those related to the resilience component at the level of internal obstacles included 100% dependence on electricity, Lack of a renewable energy supplier or system, Lack of an alternate provider (backup) of cell phones, Lack of backup data storage and cybersecurity, Lack of a backup or alternate drinking water system, other. At the external level, they were Vulnerable and/or unreliable electricity supply systems, Vulnerable and/or unreliable telecommunications systems, Weak or insufficient or short-range satellite or cable connectivity systems, and Bureaucracy of government agencies for acquiring permits and licenses for financing solar energy systems.

Finally, the interviews sought to identify aspects related to financing modes and types of non-financial aid. Puerto Rican companies were identified and selected for the Puerto Rico Parallel18 accelerator, which manages and hosts projects that facilitate entrepreneurship through grants, technical support, networking, and resources for researchers, entrepreneurs, farmers, investors, and other groups.

A sample of 39 companies was selected according to their industrial classification or economic activity, especially looking for sectors related to technology that met the following requirements: MSMEs with five years or more of operation, belonging to different business sectors, with at least 3 vectors of the 4IR incorporated in their company and with a presence on the Internet. The shortlist was sent an invitation letter by email and contacted by phone. Data triangulation was used to obtain greater quality control in the analysis process and to guarantee validity, credibility, and rigor in the results (Aguilar et al., 2015; Benavides & Gomes-Restrepo, 2005). Of the 39 MSMEs selected, 22 completed the pre-selection form, 18 agreed to be interviewed, and 18 finished the interview and data corroboration process. The entire study was conducted between October 2022 and April 2023.

The interviews show that 67% (12/18) tend to incorporate applications and software that allow them to be integrated into the network to which the business belongs. These are primarily services to the regulated health industry, whose operations are audited and controlled by the government, authorities, and regulatory agencies. This sector is characterized by harmonizing operational standards, which allows processes to be structured within a network of suppliers, auditors, and suppliers (insurers, medical equipment producers, engineers, distributors, retailers, and health professionals). These standards are determined by the industry, which requires companies or businesses to operate with operating systems, platforms, software, and equipment approved by local and federal health laws, which allows their members (entrepreneurs) to exchange data, develop regulated products and

services, security and confidentiality, market intelligence, among other functions. Although being a regulated industry guarantees the entrepreneur reliability in the data exchanged (non-duplication, updating, etc.), referrals, etc., it limits its autonomy for the acquisition of 4.0 technologies that are not authorized by the industry and its regulatory agencies, such as the Food and Drug Administration (FDA) or the European Medicines Agency (EMA). This implies that the entrepreneur is subject to constant investments, auditing, and validation processes, and the costs could rise and impact the company's competitiveness and survival. Those who determine which 4.0 technologies companies can or cannot adopt rely on the authorities that regulate the health industry. This explains why MSMEs in this sector are a priority for the adoption of 4.0 technologies, the need for digitalization with the platforms and equipment required by the industry, and thus guarantee the continuity of operations.

As can be seen in Table 1, the MSMEs mainly studied respond to the services sector, with health services standing out. Similarly, cloud computing, sensors and the Internet of Things (IoT), and *Big Data* analysis constitute the 4.0 technologies the participating companies have integrated for more outstanding performance and efficiencies in their operational processes (human resources management, payment system, accounting and finance, inventory, etc.). As with the findings reported in the study by Ascúa et al. (2021) on the case of Colombia, the technologies implemented, in process, or projected to be implemented included IoT sensors, advanced robotics, 3D additive printing, cloud computing, *Big Data analytics*, and artificial intelligence.

The MSMEs studied were developed between the initial and intermediate stages of adopting 4.0 technologies. Eight (8) recognize the need to invest in moving to a phase of technology expansion, which, according to the future projects they mentioned, mainly facilitates the application of predictive intelligence techniques to the different areas of the company.

Advanced robotics and process automation are among the 4.0 technologies that MSMEs in the regulated industry combine with those mentioned above. Some reported that these two technologies are projected to be adopted in the future. These are MSMEs in the agribusiness sector, namely ABAC and SCIEN. On the other hand, all participating MSMEs recognize that to remain competitive, financial investment in state-of-the-art technologies must be continuous to ensure continuity as a company. The participating MSMEs in the health services sector agree that the adoption of IoT, artificial intelligence, and cloud computing technologies allows them interoperability, data analysis, projections, efficiency, and effectiveness in real-time and linking with customers through virtual assistants and, in some cases, through *Customer relationship management* (CRM) software. Medical services offices, equipment manufacturers, medical devices and software, and validation and audit services stand out in this sector. Two (2) participating companies excel in implementing advanced robotics and 3D printing: DBA and INSU. The former offers medical services dedicated to studies and interventional procedures to patients with gastrointestinal, liver, kidney, or biliary tract problems. This company uses advanced robotics using a gastroscope, which they acquired in 2022, with NBI (*Narrow Band Imaging*) technology to analyze tissues more precisely. Incorporating artificial intelligence facilitates the analysis of images obtained with NBI technology.

In the case of INSU, a manufacturer of refrigerators that transport medicines that require special refrigeration, 3D printing allows different designs (prototypes) to be tested at a lower cost to improve their product. In the case of SHAPR, a manufacturer of virtual reality glasses that provide cognitive training to improve the skills of people diagnosed with autism or any user who wants to improve some other skill, such as athletes and/or others, 3D printing facilitates the creation of different prototypes that allow the incorporation of accessories and meet specific demands for other niche markets. For ADOR, the combination of 3D printing with programmed (*AutoCad, Solidworks,* and *MasterCam)* and other technologies such as CNC, Milling, EDM, and Lathe provides flexibility and speed when designing parts according to the needs of its customers and, in turn, allows it to work with different materials, such as plastic and metal (steel, *stainless steel*, etc.)., bronze, aluminum, copper, among others). In the case of BLUE, which provides engineers and scientists with auditing and validating processes and automation of the regulated industry, 3D printing has contributed to identifying attachments that result in innovations, efficiency, increased production, and quality of the audited processes. For ABAC and E-FULL, incorporating advanced robotics has improved their customer portfolio, maximized logistics and supply processes efficiency, and reduced errors and redundancy.

Table 1 New digital technology projects implemented, under implementation, or projected in MSMEs in Puerto Rico.

							Implementation level		
MSMEs	**Sector**	**Location**	**Type of project**	**Implementation**	**Project Initiation (Year)**	**Financing**	**Implemented**	**In process**	**For the future**
DBA	Health Services	San Juan	Advanced robotics, sensors and the Internet of Things, cloud computing, Big Data analytics and artificial intelligence (AI)	Advanced robotics with an NBI (Narrow Band Imaging) gastroscope for tissue analysis, using electronic records with links to perform telemedicine and virtual assistant for appointment and call management (LARA).	Electronic File (2010). Virtual Assistant (2020), Gastroscope (2022).	The surplus income is used for extraordinary investments. They do not consider external financing and receive support from academia.	X		X Update Big Data
INSU	Medical Equipment Manufacturing	San Juan	3D printing, advanced robotics, sensors and the Internet of Things, cloud computing, big data analytics, and AI.	3D printing, advanced robotics, sensors and the Internet of Things, cloud computing, big data analytics, and AI.	2018	It has received money from business organizations and the government but has not yet generated its own sales income. It has also received support from academia.	X		X Update Big Data and Advanced Robotics
ABAC	Agricultural technology	Peñuelas	Big Data, Sensors & IoT, Advanced Robotics	Documentation, analysis, and management of historical data and automation of current data. Microclimate monitoring, invoice automation collection system, and geolocation of animals and pests within the farm. Automation of the sowing and harvesting process.	2021	$125K was awarded by the business support organization Parallel18.	X Big Data		X Sensors, IoTs, and Advanced Robotics
CLIN	Medical Services	San Juan	Cloud Computing and IoTs	Archiving medical records. Communication and delivery of electronic prescriptions directly to the pharmacy.	2015	$20K Small Business Administration (SBA) Business Loan)	X		X Sensors and equipment for IoTs
ADOR	Die Cutting Services, Manufacturing for the Pharmaceutical Sector	Bayamón	3D, Laser, and WaterJet cutting machines	Part design using AutoCAD, SolidWorks, and Mastercam systems. Manufacturing metal or plastic parts with 3D cutting, Laser, and Waterjet machines	2017	Own business cash reserve and SBA loans.	X		
LABO	Biological Sample Analysis Services	Las Piedras	Digital recording, digitized communication of results, IoTs, and cloud computing.	Entry into digital cooperation agreements through the laboratory networks of Assertus Puerto Rico to establish a system of registration and delivery of results online. IoTs for Productive Online Data Availability.	2020	The corporation's funds are contributions from the owners and external capital collateralized by company or family assets.	X		
E-FULL	Digital Wholesaler	Guaynabo	Advanced Robotics, Cloud Computing, and AI	Software that facilitates accounting, customer relationship management, purchasing, and sales	2020		X Cloud Computing		X Advanced robotics and AI to facilitate inventory and warehousing operational processes

DELG	Legal Services	Rio Piedras	AI, Cloud Computing, and Big Data Analytics	AI software for case management, legal-legal data analysis, and integration of organizational areas and activities through cloud computing.	2019 (AI), 2020 (Cloud Computing), 2023 (Big Data)		X		
BERR	Technological services to Pharmaceutical, Biotechnology, Medical Devices, and Consumer corporations, among others	Caguas	IoT, cloud computing, and big data analytics	IoTs-Process automation in areas of production, marketing, and customer relations. (Ex. Customer Support); Cloud computing to facilitate the integration of organizational areas (e.g., Workflow: roles, creation of activities, and reporting). Big data integrates data from production, business (sales, inventories, logistics), validation processes, and scientific experimentation through different business intelligence platforms.	2015		X		
BRAN	Digital retail services	Guaynabo	Cloud computing, big data analytics, authentication and fraud detection, AI	Cloud computing-. Internal - Company information is in one place through a platform built in PHP (programming language) using the e-commerce library. It has several integrations through Google Analytics, Google marketing, Facebook, Apps, and hotspot integration such as CRM Big Data- Internal - Data integration through Microsoft BI for clear and timely information visualization. Authentication and Fraud	2016		X		X Additive 3D printing
				Detection-Internal—The Payment processor (always on) was purchased with the provider STRIPE, which has its own algorithm that identifies risk patterns that may indicate fraud when people are shopping (credit card thefts).					
ASPP	Health Services	San Juan	Sensors, IoTs, Cloud Computing, Big Data Analytics, AI	IoTs and artificial intelligence are used for interoperability, data analytics, and telemedicine. Cloud computing for data analysis. Big Data Analytics for 330 Center Data Analytics	2015	U.S. Department of Health State Funding	X		X (Advanced Robotics)
DIMED	Health Services	San Juan	Sensors, IoTs, Cloud Computing, Big Data Analytics, AI	IoTs for remote patient monitoring. Cloud computing via the iUGO Care platform. Artificial intelligence through a SaaS (software as a service) platform).	2020	Parent Company, Surgical Solutions Puerto Rico	X	X Big Data	
BRAIN	Health Services	San Juan	AI (chatbots), Data analytics and automation	Virtual assistant chatbot to recover missed calls. Database system to assist in monitoring, call flow analysis, and customer experience. Automation of the appointment scheduling process for clients.	2017	The owners initially financed the company. Then, it won the Start-up competition and received private funding from accelerators and incubators.	X		
SHARP	Health Services	Barceloneta	AI, Virtual Reality	AI and virtual reality systems are used to develop digital products and applications that improve customers' reactions and attention skills.	2018	Private capital of the owners. Scholarships from incubators such as Parallel18, the American Heart Association, and some entrepreneurship and development programs.	X		
SCIEN	Agroindustry	Gurabo	Big data, IoT, cloud computing, AI	Big data analytical technologies that make it easier to understand the botanical material and discover the correct chemical composition, real-time integration of processes and data.	2017		X (IoTs, cloud computing)	X AI	X (Big data, chemometric methodologies to improve the quality of botanical supplements).

SORRI	Technology Services	Carolina	Sensors, IoTs, Big data	Applications that facilitate the interconnection between customers (B2B) and end customers (B2C) through Self-Service Technology (SST) Door Dash. Cloud Based POS System Clover.	2019		X		
PHAR	Develops solutions and software for regulated industry	San Juan	IoT Sensors, Cloud Computing, and Big Data Analytics	IoT Platform Development uses Raspberry Pi devices and integrates the data with the client's ERP systems. The project was developed with its own personnel and validated in a medicine storage and distribution company.	2014		X		
BLUE	Regulated Industry Consulting and Validation Services	San Juan	Big Data Analytics & Automation, AI	Algorithms are being developed to analyze analytical qualities using innovative technologies (PAT) and infrared sensors. Automation equipment is being validated, and 3D printing is being considered.	2016		X	X AI	

Source: Author's elaboration, 2024.

As can be seen in Table 2, in order of priority, the motivations of 50% of the participants (9/18) indicate that maintaining efficiency in the company's daily operations is the first trigger to consider the adoption of 4.0 technologies; 39% (7/18) consider guaranteeing the continuity of operations through digitalization as the primary trigger, and 2/18 (12%) indicate that improving customer service and optimizing the quality of the product/service are the primary motivators, respectively. These findings coincide with some motivations reported by the cases in Colombia, Argentina, and Brazil, where the central motivators for the adoption of these technologies are to improve the efficiency of a function or process, save on costs, and improve quality (Carmona et al., 2020; Maggi et al., 2020; Motta et al., 2019). In the case of Chile, according to Maggi et al. (2020), the primary motivators in the adoption of 4.0 technologies are to improve competitive positioning, develop differentiating attributes of the offer, improve customer pre-sales, improve product quality, build customer loyalty against new competitors, update to stay current in the market and diversify their offer, which makes it easier for them to remain competitive.

It should be noted that adopting these technologies was influenced by disruptive events (hurricanes, earthquakes, and pandemics) on daily operations when the alternative of digitalization, as well as the incorporation of energy backup equipment, was critical in this decision-making. This allowed companies to offer digital registration services, telemedicine, electronic invoicing, digitized data communication, cloud storage, and cybersecurity. In the Colombian case, adopting these technologies was influenced by an external element linked to the Government and its support, in tax exemptions, to companies that adopted these technologies (Ascúa et al., 2021).

Table 2. Motivations and proceeds from the adoption of 4.0 technologies

Scale	MSMEs	#	Motivations	Proceeds
Foremost (1)	INSU, BERRY, BRAND, BRAIN, E-FULL, ADORN, SORRI, ABRAC, SCIEN	9/18 50%	Improve the company's operational processes	Efficiencies in daily operations
	ASPP, DIGIMED, DELGA, LABO, CLINI, BLUE, PHARMA	7/18 38.8%	Ensuring continuity of operations through digitalization	Competitiveness through retention and increase in the portfolio of customers and suppliers
	DBA	1/18 5.5%	Improve customer service	Efficiency and effectiveness in the relationship with the client
	SHARP	1/18 5.5%	Optimize the quality of the product or service	Product and service development
Relevant (2)	INSU, BERRY, BRAND, DIGIMED, SORR	6/18 33.3%	Cost reduction or savings	Elimination of redundancy in tasks and labor optimization
	Scale			
	I, ADORN			
	ABRAC, LABO, SCIEN, BLUE, PHARMA	5/18 27.7%	Digitization of core operations	Automation of operations
	INSU, BRAND, DIGIMED, ASPP	4/18 22.2%	Improve the relationship with suppliers	Effectiveness in the relationship and contractual relationships with suppliers
	SHARP, DIGIMED, ASPP, ADORN	4/18 22.2%	Attracting new customers with new value propositions	Expansion of the customer portfolio
	DBA, BRAND, E-FULL	3/18 16.6%	Strengthening data security	Robust and reliable system for users

Source: Author's elaboration, 2024.

Participants cited other relevant but not the main reasons for adopting technologies, achieving cost savings (33%), digitizing operations (28%), improving relationships with suppliers (22%), attracting new customers with innovative value propositions (22%) and strengthening data security (17%). It is interesting to note that for most MSMEs that belong to the regulated industry, the issue of confidentiality for information sensitivity has not been the primary motivation for most companies. However, only 3/18 (17%) incorporated the issue of security as a mechanism that benefits from a robust and reliable system, it is also interesting to note that 22% or 4 of the 18

companies indicated as a trigger to improve the relationship with suppliers, whose benefit is to improve or comply with the contractual relationships assumed as part of the business model in the regulated industry, whose actors are obliged to have their operational processes harmonized; This includes programs, equipment and cybersecurity systems. This allows them to have greater control and reliability in the exchanged data.

When analyzing the setbacks for the implementation of technologies, it is observed that the lack of qualified human resources (4/18) and capital for investment (6/18), as well as dependence on the country's energy system (4/18), were the internal obstacles highlighted by the participants, followed by dependence on external servers from customers and/or suppliers (1/18). Slow and complex implementation processes, either because they do not yet have the appropriate or updated infrastructure and/or because most of the tasks are manual (3/18. The first two internal obstacles reported here were also suggested as the most challenging by MSMEs in Nueva Ecija, Philippines, in their digital transformation (Agustin et al., 2024), in addition to resistance to change.

Regarding external obstacles, most participants mentioned instability in the energy system that the State controls under the Electric Power Authority (PREPA) as the major obstacle (11/18). The lack of financing (5/18) and the availability of qualified personnel in the labor market (2) were also added.

It is interesting to note that the resilience component (due to natural events or the country's infrastructure) was selected among the first obstacles mentioned by the participants. This should come as no surprise because the government has experienced ongoing disruptions in recent years: hurricanes (Irma and Maria in 2017), earthquakes (2020, 2021), supply chain disruptions from Hurricane Harvey in Texas (2017), and the COVID-19 pandemic (2020). These disruptions have propelled new business models in SMEs and the digitization of their most pressing operations as resilient strategies (Lozada-Contreras et al., 2022; Orengo-Serra et al., 2022). These obstacles associated with energy infrastructure hurt drinking water and telecommunications infrastructure, which depend 100% on the country's energy system, which is an obsolete and bankrupt monopoly of the State (Orengo Serra et al., 2023).

4. Discussion

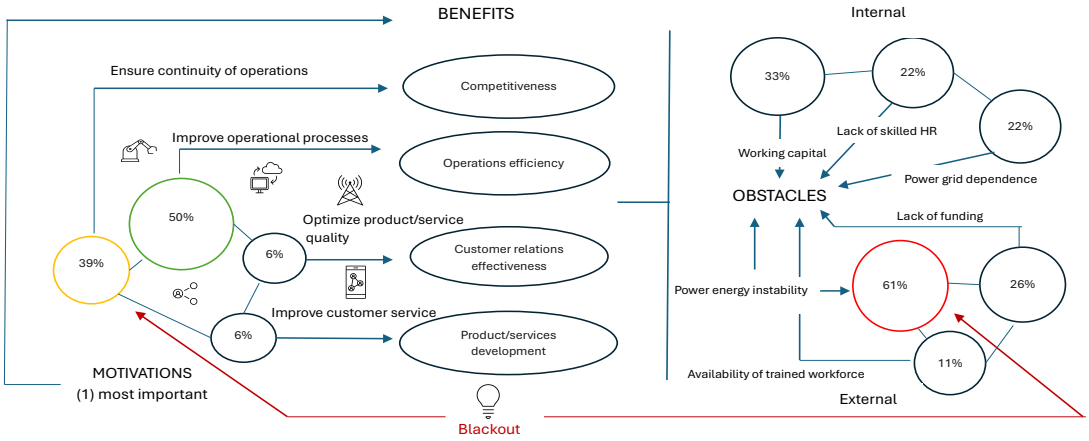
4.0 technologies are changing how we do business and impacting the performance of companies at an economic and business level (Mushtaq et al., 2023; Nor al., 2021). In this study, the adoption of 4.0 technologies responds mainly to the need to achieve efficiency and effectiveness in the company's daily operations within the challenges and obstacles they face. Challenges and obstacles include: 1. regulated industry provisions that require uniformity and interdependence of industry actors (firms), 2. accelerated changes in the industry at a global level impacted by advances in these technologies, 3. access to capital of companies for financing, 4. skilled labor, 5. dependence on a single available energy supplier, and 6. instability of the country's energy system characterized by constant blackouts that affect critical infrastructure (water and telecommunications), among other elements.

As shown in Figure 1, digitalization and the adoption of other 4.0 technologies are critical components for the survival of MSMEs and access to their backup energy infrastructure in case of frequent disruptions, thus providing autonomy and continuity of operations. The resilient infrastructure component, both energy and technology, sheds light on this issue from a geospatial approach that little research addresses, which imparts originality to this study. A disruption that affects the energy system has repercussions on the continuity and efficiency of daily operations, among others. Precisely 61% of the participants recognize that energy (see Figure 1) is the most important threat they face.

Another component is the capital required to maintain the latest generation technologies, which suggests the need for companies to have a budget allocated to technological innovations and training (Agustin et al., 2024; Nor et al., 2021). The issue of training is critical in business digitalization. A study in Pakistan found that SMEs that adopt technological advances to promote digital literacy in management and invest in digital infrastructure demonstrate greater operational efficiency and market adaptability (Mushtaq et al., 2023). Similarly, the state must develop a technological ecosystem to promote digital policies to support MSMEs in adopting technologies and digital literacy (Mushtaq et al., 2023). This ecosystem must be supported by a resilient energy and telecommunications infrastructure, which facilitates the exchange of knowledge and contact networks.

Creating an environment that develops networks of collaboration and awareness of the need to incorporate these technologies for the competitiveness and survival of companies in this 4IR must be one of the main goals of every company operating in today's business world. Technologies will be even more disruptive and changing. The profile of markets continues to evolve rapidly, so companies, especially MSMEs, are forced to insert themselves into the change, or they will be exposed to disappearing. The companies studied reflect these advances that fluctuate between incipient and intermediate stages. Healthcare industry has undergone significant transformations in recent

decades, from introducing nanotechnology medicines, precise medical devices and equipment connected to AI, telemedicine, and next-generation genomic medicine (Ahsan et al., 2022), all driven by 4.0 technologies.



Source: author's own elaboration, 2024.

5. Conclusions

This study is original because it offers an ontological approach to MSMEs adopting and implementing 4.0 technologies in a particular geomorphological environment (open island economy in the Caribbean). This environment reflects the vulnerability to which these companies are exposed. These vulnerabilities consist of a market closely linked to the United States, constant exposure of companies to natural disruptions – storms, hurricanes, earthquakes – that affect the supply chain, a complex and costly business climate for the development and positioning of MSMEs, competition from subsidiaries of business groups in the regulated industry due to the free market provided by the legal relationship between the United States and the territory, and the exodus of professionals to the metropolis in search of better working conditions.

Because 4.0 technologies and MSMEs in the Caribbean are rarely addressed, this research contributes to the scientific legacy of the phenomenon with practical and theoretical implications. On a practical level, the study sheds light on the technological instances in which MSMEs operate, which allows policymakers and practitioners operating in similar environments to develop projects and initiatives, enabling systematic and progressive insertion of MSMEs in the digital business world. On the other hand, this study opens a space for the employment of quantitative methodologies that enable the extension of the research to a broader and more representative sample for various industrial sectors in a transversal, comparative, national, and international scope.

As observed in this study, AI is a 4.0 technological vector that has assisted in developing other technologies widely used by MSMEs. AI expands the possibilities for many economies to move towards R&D of products and services with 4.0 technologies. However, global hardware and software monopolies by a tiny group of big tech companies represent a challenge for governments and companies, particularly MSMEs, the most significant contributor to GDP (UNESCO, 2022). A future additional line of research could unlock the debate on whether MSMEs in the region will continue to consume these technologies or will be able to move towards the process of absorption and creation of knowledge as a gateway to playing a leading role in specific niche markets for the region (UNESCO, 2024).

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Xenocentrism and ethnocentrism on travel destination's purchase intentions in South Africa: Consumer behavior post-pandemic

Alpheaus Litheko[1]

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[1] North-West University; School of Management; South Africa; Litheko.Litheko@nwu.ac.za
*Correspondence: Litheko.Litheko@nwu.ac.za

Abstract: This study explored the role of xenocentrism (XEN) and ethnocentrism (ETH) theories in the decision-making process for travel destinations for South African tourist consumers. This study aimed to investigate the impact of XEN and ETH on attitude towards the product (ATP) and perceived purchase intention (PPI) and the role of motivation (MOT) and information (INF) in those relationships. An online survey was used to collect the data for this study, and it was analyzed using CFA and SEM. Findings indicate that XEN impacts ATP for foreign products, resulting in a preference for imported goods. In contrast, ETH significantly impacts PPI, encouraging people to prioritize domestic products. Also, MOT influenced PPI and mediated the relationship between INF and PPI, and INF influenced MOT, ATO, and ETH. Managers should use cultural sensitivity in marketing strategies to target foreign and local consumers with unique tastes and beliefs and enhance perceived value through high-quality products and local sourcing. Emphasizing foreign characteristics in xenocentric markets and local sourcing in ethnocentric markets can enhance perceived value.

Keywords: Consumer behavior, destination management organization, ethnocentrism, perceived purchase intention, xenocentrism

1. Introduction

Touristic attractions are supported by Destination management organizations (DMOs), which are teams of professionals that lead and coordinate all stakeholders, particularly tourism businesses. DMOs collaborate with various industry players to establish a desirable image for a destination for investment and development purposes or enhancing tourism. According to Morrison (2013), effective destination management involves strategic planning and continual monitoring and evaluation of progress regarding strategies and tactics. Today, DMOs should lead in marketing and be strategic leaders in destination development. This role requires driving and coordinating destination management activities within the framework of a coherent strategy (Fyall & Garrod, 2020).

Consumer information and the effects of XEN and ETH are indispensable for strategic management. Furthermore, XEN and ETH are essential to consumer decision-making since they directly affect consumers' attitudes and perceptions toward a particular destination. Therefore, it can be argued that the concepts of XEN and ETH can play an essential role in studying consumer behavior at different levels of the consumption process (Camacho et al., 2020, 2022a). Moreover, acquiring information and knowledge of consumers' attitudes toward products, perceptions, and motivation will assist destination management organizations in formulating well-defined strategies. DMOs, as explained by Morrison (2013), should not only lead in marketing but must also be strategic leaders in destination development. This role requires them to drive and coordinate destination management activities within the framework of a coherent strategy.

This study aims to analyze the effects of XEN and ETH on consumers' decision-making processes when evaluating travel destinations. In addition, the research analyzed the relations of these two constructs, establishing a research model that integrates motivation (MOT), information (INF), and attitude towards the product (ATP) to explain their influence on consumers' purchase intention of touristic packages. Consumer xenocentrism and ethnocentrism are increasingly essential to understand from a sociological, psychological, and marketing perspective since they directly affect consumer attitudes toward products, perception, motivation, how they acquire information, and, ultimately, their purchasing choice. The research questions formulated for the study:

- Do xenocentrism or ethnocentrism positively influence South African tourists' purchase intention?
- Do xenocentrism or ethnocentrism positively influence consumers' motivation, attitude, and information-gathering about purchasing a travel destination?

Although there is limited research on how the two variables could be used for strategic management, this research has been undertaken to understand the effects of XEN and ETH on consumers and how DMOs in South Africa could plan in response to new challenges within the context of a pandemic such as COVID-19, as this necessitates developing sustainable strategies for industry performance.

2. Literature Review

Destination Management Organizations (DMOs) serve as coordinators and facilitators of a shared strategy, functioning as a "coalition of diverse interests working towards a common goal, ensuring the sustainability and unity of their destination both presently and in the future," as proposed by Romao et al. (2021, p. 81). South African Tourism (2022) recommended that DMOs shift from purely a destination marketing focus to a destination management focus, requiring a strategic management approach to be more resilient to potential disruptions, such as the COVID-19 pandemic. Further, effective destination management will facilitate coordinating many stakeholders' efforts to achieve a destination's vision and goals (Morrison, 2013). Nevertheless, both nations and individuals are not immune to the impacts of global transformations, as seen by the repercussions of the COVID-19 epidemic.

The COVID-19 pandemic has resulted in numerous adverse ramifications on a global scale, as highlighted by Mensah and Boakye in 2021. In addition to the health issues affecting the population, the pandemic has resulted in various consequences, such as a decline in economic activities, a global economic crisis, movement restrictions, economic shutdowns, quarantine measures, the collapse of numerous companies, and bankruptcy of well-known brands, as well as a significant loss of jobs for many individuals (Mahmoud et al., 2021). Zwanka and Buff (2020) documented changes in consumer behavior during a pandemic, including an increase in snobbish attitudes, a rise in internet shopping, a shift towards remote employment, a preference for cooking at home, a greater emphasis on environmental responsibility or seeking out new experiences, and a heightened pursuit of pleasure. According to Lau et al. (2020), travel has been recognized as a significant contributor to the worldwide dissemination of infectious diseases. Therefore, numerous researchers have focused their attention on the alterations in travel patterns resulting from COVID-19 and other such epidemics, as Paul et al. (2021) noted.

2.1 Effects of Xenocentrism on Consumer Behavior

Xenocentrism (XEN) originated in sociology literature and was first regarded as a complement to ethnocentrism. It defines individuals who appreciate a civilization distinct from their own and judge everything using that society as a reference point (Diamantopoulos et al., 2019). XEN, in the context of consumption, refers to the inclination of customers to select items or services from a society different from their own. Hence, consumer xenocentrism denotes the inclination of consumers toward foreign products and their dismissal of home alternatives (Cucato et al., 2022). According to Camacho et al. (2022a), the phenomenon of local purchasers choosing imported products over local ones, even if the local products are of comparable quality and usefulness, is referred to as xenocentrism (XEN).

XEN's study focuses on global identity, which refers to consumers' beliefs about the effects of globalization, the variations and commonalities among individuals, and the diversity of Earth's functions, as described by Rojas-Méndez and Chapa (2019). Conversely, Camacho et al. (2022a) highlighted that individuals with a global identity are intensely interested in matters about communities, groups, and global communities. XEN is the phenomenon where individuals prioritize purchasing international things over local products, associating their global identity with this choice. The justification for XEN arises when the global identity is related to the preference for foreign items, which has a detrimental impact on local products, as elucidated by Camacho et al. (2022a).

H1a. XEN directly influences ATP
H1b. XEN directly influences PPI
H1c. XEN mediates the relationship between INF and PPI
H1d. XEN mediates the relationship between INF and ATP

2.2 Effects of Ethnocentrism on Consumer Behavior

ETH, or ethnocentrism, is a widely observed sociopsychological characteristic characterized by the inclination to evaluate other cultures according to the criteria of one's own culture and the assumption that one's ethnic and cultural group is superior to others (Alsughayir, 2013). Consumer ethnocentrism, as defined by Camacho et al. (2022b), refers to the belief held by specific consumers that buying products made in foreign countries is detrimental to the domestic economy, leading to job losses and being unpatriotic. This perception is particularly prevalent in emerging economies like South Africa (Boukamba, Oi, & Sano 2021). According to researchers, customers in emerging economies are strongly inclined toward foreign items, even when they are more expensive and of lesser quality (Akbarov & Cafarova, 2021; Diamantopoulos et al., 2019). According to Balabanis and Diamantopoulos (2016), customer XEN prefers buying pricey imported products while ignoring locally made goods that are either identical, of greater quality, and cheaper. Evaluating Consumer XEN and ETN is crucial for developing and executing efficient management plans and investing in the local economy.

H2a. ETH directly influences ATP
H2b. ETH directly influences PPI
H2c. ETH mediates the relationship between INF and PPI
H2d. ETH mediates the relationship between INF and ATP

2.3 Influence of psychological factors on consumer behavior

Psychological variables greatly influence the behavior of tourists. These elements explore the underlying intentions, mindsets, viewpoints, and feelings that influence people's travel and tourism decisions, as Santos et al. (2022) explained. According to Shareef et al. (2023), to comprehend the psychological aspects of tourism post-COVID-19, one must consider the challenges and changes in consumer behavior brought about by the epidemic. These are some of the psychological variables that influence consumer behavior in the tourism sector:

2.3.1 Information

Searching for information is one of the first stages of purchasing. Traditionally, information search has been considered essential to consumers' decisions. Solomon (2019) defines information search as the deliberate process of obtaining information from one's surroundings, suggesting that underlying factors drive this urge to search. Consumers who search for information are driven by anticipated values or benefits, which aid them in making more informed purchasing decisions (Gvili et al., 2020). Furthermore, studies indicate that the value of information favors customers' behavior and the effort they are willing to invest in searching for information (Kol et al., 2021). Consumers make significant efforts to search for information to reduce the uncertainty of purchasing a tourist package (Garcia-Milon et al., 2020). Therefore, DMOS must understand methods consumers use to search for information as this will inform the communication strategies for the tourism sector and, more importantly, have communication strategies that will address the needs of consumers during the pandemic.

H3a. INF directly influences XEN
H3b. INF directly influences ETH
H3c. INF directly influences ATP
H3d. INF directly influences MOT
H3e. INF directly influences PPI

2.3.2 Motivation

Motivations have been a significant subject of study in tourism and consumer behavior due to their ability to stimulate and direct human actions (Caber & Albayrak, 2016). Existing literature on tourism suggests that travel motivations play a crucial role in influencing travelers' decision-making processes and are significant factors in determining their spending behaviors (Hsu et al., 2016).

The motivation variable significantly influences post-COVID-19 travel package buying intentions. Motivation describes the underlying causes or forces that propel consumers to carry out actions, such as buying a travel package, as Reeve (2016) described. For DMOs to effectively design offerings, communicate value propositions, address health and safety concerns, and create memorable and meaningful experiences that meet consumers' expectations, they must have a thorough understanding of the post-COVID-19 motivations of consumers (Majeed & Ramkisson, 2022).

In addition to motivation, the consumer's decision-making process is influenced by various additional elements (Svatosová, 2013). Hence, marketing professionals must comprehend these consequences and their significance to devise impactful marketing tactics. Social conditions, wants, supply, habits, selling strategies, and technology influence this point. The role of a marketing specialist is to identify the cognitive process that

customers go through, from considering a purchase to making a final choice, known as the stimulation process. Furthermore, the determinants that impact consumer behavior can be categorized into external and internal components. External elements encompass cultural, socioeconomic, and demographic aspects, while interior factors encompass subjective and psychosomatic factors. Nevertheless, each person's buying is influenced by four psychosomatic factors: learning, motivation, perception, and attitude. Customer motivation is a crucial component that heavily influences their final purchasing decision. Nevertheless, it is a prime component influencing consumer purchasing behavior (Orji et al., 2017).

H4a. MOT directly influences PPI.
H4b: MOT mediates the relationship between INF and PPI

2.3.3 Attitude towards product

An attitude can be defined as a comprehensive evaluation of a psychological item based on many characteristics such as positive-negative, detrimental-beneficial, enjoyable-unpleasant, and preference-dislike (Ajzen, 2001). Prior studies have investigated consumer ATP. For instance, Grohmann et al (2007) examined the emotional and pleasure-related components of consumer ATP, whereas Liu et al. (2017) evaluated the cognitive and practical elements. In addition, Luangrath et al. (2022) focused on the behavioral intents and evaluative aspects of product attitudes. The attitude variable impacts customer behavior and intentions to acquire trip packages, specifically in the aftermath of the COVID-19 pandemic.

A person's total assessment, sentiments, and convictions regarding a good or service, considering factors like satisfaction, quality, value, and advantages, are referred to as their attitude (Shareef et al., 2023). According to Camacho et al. (2022a), an individual's attitude toward behavior relates to their subjective evaluations about adopting a specific behavior, which can be either negative or positive. In the post-COVID-19 era, consumers' perceptions regarding safety protocols, experience quality, value for money, brand reputation, customer service, digital experience, and emotional appeal (Shareef et al., 2023) substantially influence their buying intentions of tourism packages.

H5a. ATP directly influences PPI
H5b. ATP mediates the relationship between XEN and PPI
H5c. ATP mediates the relationship between ETH and PPI
H5d. ATP mediates the relationship between INF and PPI

2.3.4 Purchase intention

Purchase intention refers to the probability that consumers will intend or be inclined to buy a specific product or service in the future (Wu, Yeh, & Hsiao, 2011). Previous studies have shown that a higher purchase intention indicates a higher likelihood of purchasing. Favorable brand engagement positively influences consumers' purchase intention, leading to an increased likelihood of purchase. When discussing smartphones, it is essential to consider the concept of purchase intention, which refers to the inclination of customers to buy anything via a mobile application (Chen et al., 2010).

Empirical scientific studies on purchase intentions have provided insights into the customer behavior process and identified factors influencing consumer purchase intentions, such as experience, educational attainment, social class, and social acceptance and involvement (Camacho et al., 2022a). According to the study conducted by Camacho et al. (2020), consuming a travel package can either enhance or decrease purchase intentions due to the direct influence of interpersonal relationships. The consumer's intention to buy is also high when the quality is excellent. DMOS must comprehend the psychological factors influencing consumer behavior after the COVID-19 pandemic. This understanding will enable DMOs to adjust their strategies to accommodate tourists' changing needs and preferences. By developing a well-informed strategy, DMOs can contribute to the sustainable growth of the tourism sector in South Africa.

3. Methods

3.1 Sample and procedure

An online structured computer-administered survey was used to collect the data for this study. The target population was traveling consumers aged 21 years and above residing in South Africa who have traveled in or outside South Africa since 2017. The study had a sample size of 400, and the quantitative method employed a non-probability convenient sampling approach. It is a technique that depends on gathering data from a readily accessible population to conduct a study (Gobo & Mauceri, 2014). Non-probability sampling involves a sampling technique where the probability of selecting a participant from the population is unknown. Convenience sampling was utilized in this research, applying specific inclusion criteria mentioned in the above section. The study received ethical approval from the Economics and Management Sciences Research Ethics Committee (EMS-REC) of the North-West University, and the ethics number (NWU-00647-23-A4). The foundation theories for

this study are XEN and ETH, and respondents provided information about the two constructs from a tourism perspective. Participants also provided information on how XEN and ETH influenced their decision-making to purchase a travel destination.

3.2 Measures

The constructs of xenocentrism (Rojas-Méndez & Chapa, 2019) and ethnocentrism (Shimp & Sharma, 1987) contained scales from previously validated research. Information and Motivation were determined using the scales retrieved from Sanz de Acedo Lizarraga et al. (2009), which was a vital departure point to determine the motivation levels in purchasing a tourist package among South African consumers. The ATP of purchasing a tourist package was measured by adapting the scale from Kim (2000). Lastly, the "purchase intention" was determined by adjusting the scale from Chaudary et al. (2014). All these items were measured on a 6-point Likert-type scale, where 1=strongly disagree; 6 =strongly agree.

The researchers received 598 questionnaires, but 198 had to be discarded since they lacked crucial data for this study. Regarding gender, 33 percent of the participants were male, and 67 percent were female. Regarding age, 51.3 percent of participants identified as 21-30 and 36.5 percent as 31-40. Regarding educational attainment, 49 percent reported % a bachelor's degree and 34.8 percent a Postgraduate degree. Additionally, 95.5 percent of participants live in urban areas, and 4.5 percent live in rural areas.

4. Results

A preliminary analysis was conducted to explore the research subjects utilizing all the variables included in the study. The analysis was performed via descriptive statistics and correlation analysis, employing IBM's SPSS software. Subsequently, the internal consistency of the measurements was assessed by computing Cronbach's alpha coefficients. The threshold for acceptable internal consistency of the items was determined to be a Cronbach's alpha value greater than 0.7, as outlined by Kline (2015). The validation of the measurement devices was performed using Confirmatory Factor Analysis (CFA) in AMOS version 28. Multiple model fit indicators were utilized to assess the suitability of the measurement model. The model was enhanced by using modification indices recommended by AMOS. Convergent and discriminant validity assessment used composite reliability, average variance extracted, maximum shared variance, and maximal reliability.

Table 1 displays the computed values for means (M), standard deviations (SD), dependability coefficient (CA) (expressed by Cronbach's alpha), and correlations among the variables investigated in the study. ATP has the highest reliability of 0.81, followed closely by MOT, with a reliability value of 0.79. On the other hand, XEN has the lowest reliability value of 0.709. Furthermore, the variable MOT has the highest average value of 5.15 in the dataset, while ETH has the lowest mean value of 3.69. The SD measures the degree of dispersion of the scores from the mean. XEN and ETH display the highest standard deviation values (1.21 and 1.20, respectively), indicating that their responses have more significant variability than the other variables.

Table 1. Descriptive statistics

	XEN	ETH	INF	MOT	ATP	PPI
M	3.76	3.69	4.85	5.15	4.74	5.10
SD	1.21	1.20	.93	.72	.81	.85
CA	.709	.748	.729	.799	. 815	. 762
			Correlations			
XEN	1	.939**	.180**	0.049	0.094	.157**
ETH	.939**	1	.140**	0.004	0.032	.144**
INF	.180**	.140**	1	.429**	.357**	.253**
MOT	0.049	0.004	.429**	1	.407**	.398**
ATP	0.094	0.032	.357**	.407**	1	.328**
PPI	.157**	.144**	.253**	.398**	.328**	1

** Correlation is significant at the 0.01 level (2-tailed).

Table 1 shows that the highest positive correlation in the data was between XEN and ETH ($r = .939$, $p < 0.01$), indicating the importance of xenocentric and ethnocentric attitudes on the South African consumer's decision process when purchasing travel destinations. The lowest positive correlation was between INF and ETH ($r = .140$, $p < 0.01$). The correlations were used as a first means of assessing the previously anticipated links' magnitude and direction, and they were not construed as proof of causation.

Confirmatory factor analysis (CFA) is a widely acknowledged and necessary technique in structural equation modeling (SEM) for validating measurement models in both route and structural studies (MacCallum et al., 2010). Table 2 displays the evaluation of the construct's reliability. Construct reliability is considered high when

composite and maximum reliability ratings are over 0.7. Convergent validity is established when the composite reliability exceeds 0.7, and the average variance retrieved surpasses 0.5, as Malhotra and Dash (2011) stated. According to Gaskin and Lim (2016), the model should have an average variance extracted that exceeds 0.5 and a MaxR(H) (Maximal Reliability) that exceeds 0.7. Therefore, Table 3 clearly illustrates the dependability and accuracy of the model.

The measurement model was tested using AMOS through Confirmatory Factor Analysis (CFA). Within the framework of the CFA, factor loadings were evaluated for each item. The items XEN3, XEN4, ETH1, ETH2, ETH3, and ATP8 were excluded since they exhibited low factor loadings (<.50). The model-fit metrics, including CMIN/df, GFI, CFI, TLI, SRMR, and RMSEA, were utilized to evaluate the model's overall goodness of fit. All of these values were found to be within the predicted acceptance thresholds as defined by Ullman (2007). Table 2 presents the results of the six-factor model, which includes Xenocentrism, Ethnocentrism, Information, Motivation, Attitude Toward Product, and Perceived Purchase Intention. The model demonstrated a solid fit for the data, as indicated by the following statistics: CMIN/df = 2.113, GFI = .934, CFI = .944, TLI = .928, SRMR = .053, and RMSEA = .053.

Table 2. Model fit measures

Factor/Item	FL	CR	AVE	MSV	MaxR(H)
Xenocentrism		0.714	0.557	0.139	0.727
XEN5	0.69				
XEN6	0.799				
Ethnocentrism		0.751	0.504	0.052	0.763
ETH4	0.765				
ETH5	0.619				
ETH6	0.736				
Information		0.729	0.574	0.321	0.729
INF3	0.756				
INF4	0.76				
Motivation		0.804	0.51	0.321	0.83
MOT1	0.655				
MOT2	0.844				
MOT3	0.622				
MOT4	0.715				
Attitude Toward Product		0.83	0.551	0.23	0.849
ATP1	0.711				
ATP3	0.699				
ATP4	0.692				
ATP5	0.856				
Perceived Purchase Intention		0.764	0.52	0.262	0.772
PPI2	0.646				
PPI4	0.745				
PPI6	0.766				

Notes: FL: Factor Loading; CR: Composite reliability; AVE: Average Variance extracted; MSV: Maximum shared variance; MaxR(H): Maximal Reliability

The study evaluated discriminant validity by employing the Heterotrait-Monotrait (HTMT) Ratio, a method that is becoming more common. When assessed using the HTMT ratio, all ratios were below the specified threshold of .85 (Henseler, Ringle, & Sarstedt, 2015). Thus, discriminant validity was established. Table 3 displays the findings of discriminant validity.

Table 3. HTMT analysis

	XEN	ETH	INF	MOT	ATP	PPI
XEN						
ETH	0.142					
INF	0.072	0.146				
MOT	0.033	0.012	0.428			
ATP	0.307	0.038	0.357	0.407		
PPI	0.104	0.148	0.253	0.398	0.328	

4.1. Structural model assessment

We incorporated all the control variables into our analyses to mitigate the potential endogeneity in the structural equation model. The independent variables consist of age, gender, education, and income. A structural equation model created using AMOS was employed to examine the link. A fitting model is considered excellent if the CMIN/df value is less than 5 and if the goodness-of-fit indices (GFI) (Hair et al., 2017), the Trucker and Lewis (1973) index (TLI), and the confirmatory fit index (CFI) (Ullman, 2007) are more significant than 0.90 (Hair et al., 2017). Furthermore, a model was considered suitable if the estimated value of the standardized root mean square residual (SRMR) in AMOS was less than 0.05 and the root mean square error approximation (RMSEA) fell between the range of 0.05 to 0.08 (Hair et al., 2017). All structural equation modeling (SEM) indices meet the required criteria: CMIN/df = 2.312; GFI = .925; TLI = .915; CFI = .932; SRMR = .065; and RMSEA = .057.

The investigation evaluated the effect of XEN on ATP, which was shown to be positive but not statistically significant (b= .043, t = 5.59, p <.001). As a result, H1a was confirmed. The effect of XEN on PPI was positive but statistically insignificant (b= .044, t = 1.13, p = .257). Therefore, H1b was not supported. The effect of ETH on ATP was positive but not statistically significant (b = 0.035, t = -1.78, p = 0.074). Therefore, H2a was not substantiated. ETH's effect on PPI was positive and statistically significant (b= .038, t = 2.76, p = .006). This supports hypothesis H2b. The influence of INF on XEN was positive but statistically negligible (b= .087, t = 1.28, p < = .198). Therefore, H3a, which hypothesized a considerable impact, was not supported. The influence of INF on ETH had a positive and statistically significant effect (b= .095, t = 2.07, p < = .038). This supports hypothesis H3b. The influence of INF on ATP had a favorable and substantial effect (b = .062, t = 7.11, p < .001); H3c was corroborated. The influence of INF on MOT was positive and statistically significant (b= .058, t = 7.96, p < .001). Thus, H3d was confirmed. The influence of INF on PPI was positive but statistically negligible (b= .089, t = -.369, p = .712). As a result, H3e was not supported. The effect of MOT on PPI was positive and statistically significant (b= .104, t = 4.85, p < .001). Thus, H4a was confirmed. The effect of ATP on PPI was shown to be positive and statistically significant (b= .076, t = 2.73, p = .006). Therefore, this supports hypothesis H5a. Table 4 displays the model fit indices and the hypotheses' findings.

Figure 1 and Table 4 depict the mediation analysis. The study assessed the mediating role of Xenocentrism (XEN) on the relationship between Information (INF) and Perceived Purchase Intention (PPI) (b=.006, t=.54, p = .238) and the relationship between Information and Attitude Toward Product (b=.027, t= 1.03, p = .182). The results revealed no mediation effects for either relationship. Therefore, hypotheses H1c and H1d were not supported. The mediating role of ETH on the relationship of INF and PPI (b=.021, t= 1.31, p = .062) and INF and ATP were (b= -.012, t= -1, p = .09) measured; the results revealed no mediation effect for both relationships. Therefore, hypotheses H2c and H2d were not supported.

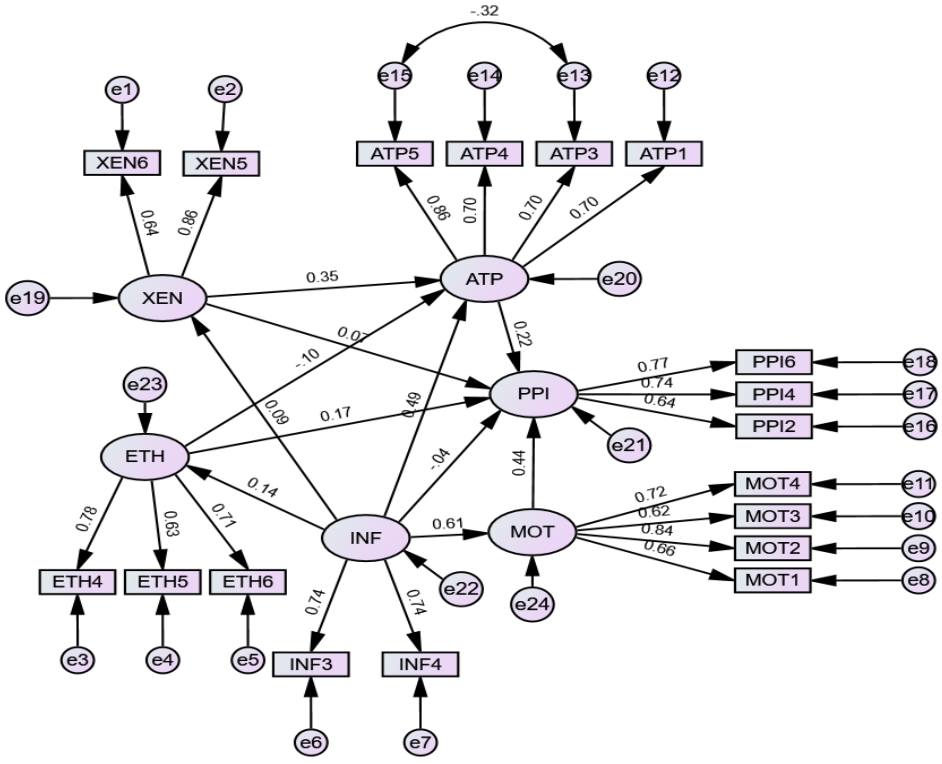

Figure 1. Structural Equation Model

Table 4. Hypotheses validation

	Hypothesis	Standardized Estimate	p-Value	Decision
H1a	ATP ←-XEN	0.043	***	Supported
H1b	PPI ←-XEN	0.044	0.257	Not supported
H2a	ATP ←-ETH	0.035	0.074	Not supported
H2b	PPI ←-ETH	0.038	0.006	Supported
H3a	XEN ←-INF	0.087	0.198	Not supported
H3b	ETH ←-INF	0.095	0.038	Supported
H3c	ATP ←-INF	0.062	***	Supported
H3d	MOT ←-INF	0.058	***	Supported
H3e	PPI ←-INF	0.089	0.712	Not supported
H4a	PPI ←-MOT	0.104	***	Supported
H5a	PPI ←-ATP	0.076	0.006	Supported

	Mediation Analysis						
	Relationship	Direct Effect	Indirect Effect	Confidence Interval		P-Value	Decision
				Lower Bound	Upper Bound		
H1c	INF → XEN → PPI	0.089	0.006	-0.003	0.041	0.238	No Mediation
H1d	INF → XEN → ATP	0.062	0.027	-0.005	0.08	0.182	No Mediation
H2c	INF → ETH → PPI	0.089	0.021	0.002	0.053	0.062	No Mediation
H2d	INF → ETH → ATP	0.062	-0.012	-0.045	0	0.091	No Mediation
H4b	INF → MOT → PPI	0.089	0.233	0.137	0.385	0.001	Mediation
H5b	XEN → ATP → PPI	0.044	0.051	0.001	0.125	0.084	No Mediation
H5c	ETH → ATP → PPI	0.038	-0.013	0.003	0.206	0.084	No Mediation
H5d	INF → ATP → PPI	0.089	0.092	0.003	0.206	0.084	No Mediation

The mediating role of ATP on the relationship of XEN and PPI (b=.051, t= 1.37, p = .084), ETH and PPI (b= -.013, t= -1, p = .084), and INF and PPI (b= .092, t= -1.48, p = .084) measured; the results revealed no mediation effect for any relationship. Therefore, hypotheses H5b, H5c, and H5d were not supported. Finally, the mediating effect of MOT on the relationship of INF and PPI (b= .233, t= 3.06, p = .001) was supported. Hypothesis H4b is supported. This result is significant for decision-makers in the tourist industry because as customers receive more information about the tourist destinations, purchase intention increases and is favorable.

5. Discussion

5.1 Theoretical implications

The study reviewed the effects of XEN and ETH on consumers' decision-making processes when evaluating travel destinations integrating MOT, INF, and ATP in a research model to explain their influence on consumers' purchase intention of touristic packages. Evaluating XEN in travel destinations is a novelty, although the other variables of the model have been tested in different studies.

This study makes the following contributions to the literature. First, XEN and ETH profoundly and uniquely impact consumer behavior. The validation of Hypothesis H1a demonstrates a direct correlation between ATP and XEN, implying that customers who prefer foreign products are more likely to judge them positively. These findings are aligned with Diamantopoulos et al. (2019) and Camacho et al. (2022a). Nevertheless, there was no backing for H1b, suggesting that XEN does not considerably influence PPI. The difference in consumer preferences for foreign products does not necessarily result in higher purchasing levels, potentially due to price sensitivity or perceived value.

Second, while ETH has a limited effect on ATP (H2a was not supported), it does have a notable influence on PPI when affordability is emphasized (H2b confirmed). These findings are aligned with Alsughayir (2013). This implies that ethnocentric customers may not automatically hold unfavorable opinions towards foreign

Products but instead actively purchase local products when they regard them as economically beneficial or patriotic.

Third, the endorsement of hypotheses H3b, H3c, and H3d emphasizes the significance of INF in influencing consumer behavior. Consumers who are firmly inclined to acquire INF are more inclined to generate positive opinions about products and exhibit greater engagement in purchasing. These findings highlight the need to make well-informed decisions when consumers make purchases, especially in industries like tourism, where perceptions of safety and value after the pandemic have a crucial impact on customer behavior. These findings are aligned with Gvili et al. (2020) and Solomon (2019).

Fourth, the mediation analysis revealed a noteworthy relationship between INF, MOT, and PPI, highlighting the indirect impact of motivational factors on purchase intentions through information acquisition. This pathway demonstrates that implementing communication and marketing methods that effectively address consumers' motivational demands and informational requirements can significantly increase their intention to purchase. Strategically, the findings indicate that DMOs and marketers should prioritize effectively and precisely disseminating information aligned with consumer motives and attitudes. Moreover, acknowledging the combined impacts of XEN and ETH on consumer behavior might assist marketers in customizing their strategies based on their target markets' cultural and psychological characteristics.

5.2 Managerial implications

The study's findings on the impact of XEN, ETH, and psychological aspects on customer behavior have significant strategic implications for managers in various industries, especially those operating in global marketplaces and the tourism sector. Gaining insight into these processes can assist in formulating more efficient marketing strategies and product positioning to synchronize with consumer preferences and cultural orientations.

Managers ought to integrate cultural sensitivity into their marketing tactics. When addressing consumers focused on foreign cultures, highlight the foreign characteristics and perceived high-quality items. On the other hand, when targeting ethnocentric consumers, marketing techniques should focus on promoting national pride, highlighting the advantages of local products, and encouraging support for the domestic economy. Customizing marketing messaging to correspond with these cultural inclinations can amplify consumer involvement and allegiance.

The various behaviors influenced by XEN and ETH indicate the necessity for precise market segmentation and focused marketing campaigns. Managers should utilize these cultural factors to divide their audiences more efficiently and create focused tactics that attract each segment's distinct tastes and beliefs. Managers should consider these cultural effects when engaging in product development and innovation. In xenocentric marketplaces, incorporating or emphasizing foreign characteristics in products or services can be a significant distinguishing factor. In ethnocentric markets, emphasizing local sourcing and showcasing local advantages can enhance the perceived value.

To improve information accessibility, managers must guarantee that comprehensive and easily accessible information about products and services is readily available to consumers. This is crucial because information search greatly influences consumer decision-making. This entails enhancing digital platforms to facilitate easy access to information and guaranteeing transparency in marketing communications.

Comprehending the motivations in consumer behavior is essential to identify the driving forces behind consumer purchases. Managers should strive to understand the driving forces behind consumer motivation, such as sustainability, quality, cost, or cultural aspects, and adapt their marketing and operational strategies accordingly.

In the epidemic's aftermath, strategic digital marketing utilization is paramount. Managers should use digital tools to meet consumer safety, convenience, and value demands. Social media, focused advertising, and digital customer service can effectively cultivate trust and benefit consumer behavior.

On the other hand, it is crucial to ensure that marketing and sales personnel possess a deep understanding of cultural dynamics and consumer psychology. Training programs that augment comprehension of XEN, ETH, and other consumer behavior theories can boost team efficacy in managing different client bases.

Managers should prioritize establishing enduring consumer relationships by actively addressing their changing needs and expectations. This entails ongoing market research to monitor consumer trends and habits and adjust strategy accordingly.

6. Conclusions

This study has explored the complex dynamics of consumer behavior, emphasizing the critical roles of XEN and ETH and key psychological factors. By thoroughly analyzing empirical data and incorporating theoretical perspectives from writers like Diamantopoulos et al. (2019), Camacho et al. (2020), and Gvili et al. (2020), we have comprehensively learned the determinants influencing consumer preferences and buying choices in a globalized marketplace.

The results of our study emphasize that XEN has a considerable impact on consumer attitudes towards foreign items, often resulting in a preference for imported goods regardless of their resemblance in quality and functionality to local products. This phenomenon is mainly fueled by customers' fascination with foreign cultures and a strong preference for foreign products as indicators of superior quality or social standing. In contrast, ETH encourages people to prioritize domestic products driven by a feeling of patriotism or economic allegiance. This inclination is magnified in developing economies because buying native products is frequently interwoven with patriotic sentiments and concerns for local job opportunities, especially in times of crisis.

Psychological factors, such as motivation and information seeking, have significantly influenced consumer actions. Motivations are intricately connected to individual and societal variables that compel consumers to make particular buying choices. Furthermore, searching for information has transformed into a crucial stage in consumers' decision-making process, allowing them to match their buying habits with their values and perceived advantages.

Mediation analysis yielded further insights, demonstrating that MOT and INF considerably influence customer purchasing intentions through intricate pathways. These findings indicate that consumer behavior is influenced not just by cultural predispositions but also by how these predispositions interact with psychological drivers.

The research highlights the significance of marketing tactics, considering cultural and psychological factors. Marketers and DMOs, especially in the tourism industry, can enhance their marketing tactics by comprehending these behavioral motivators. This understanding enables them better to address the varied consumer requirements in a world recovering from the epidemic.

7. Limitations and future research

This study was conducted in South Africa, and future research should apply and test this study's model with more representative samples and countries with different backgrounds. Also, longitudinal studies are recommended for future research to monitor and analyze changes in consumer behavior over an extended period. This methodology would facilitate comprehension of the enduring effects of such occurrences on consumer inclinations and conduct. Expanding research to encompass a wide range of cultural and economic situations can boost the generalizability of the findings. Research that explicitly examines places not well-represented or compares consumer habits across major cultural divisions might provide valuable insights into how culture influences consumer behavior globally.

Given the growing impact of digital technology on consumer behavior, future studies must investigate the effects of digital platforms and social media on individuals' views of foreign and domestic products. This entails examining the impact of internet evaluations, social influence, and digital marketing on changing customer attitudes towards xenocentrism and ethnocentrism.

Exploring the impact of global identity on consumer behavior beyond the XEN and ETH dichotomy could offer valuable insights into how consumers view themselves and others in a worldwide economy. A potential area of research might explore the impact of global citizenship on consumer behavior and brand loyalty in international markets.

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University and social context and their influential impact on entrepreneurial intention in Latin America.

Guillermo vanderLinde [1], Tamara Mera [2], Ruiz, R.Y.[3]*

[1]Pontificia Universidad Católica Madre y Maestra, Dominican Republic; guillermovanderlinde@pucmm.edu.do
[2]Pontificia Universidad Católica Madre y Maestra; Dominican Republic; tamaramera@pucmm.edu.do
[3]Pontificia Universidad Católica Madre y Maestra; Dominican Republic; rosaruiz@pucmm.edu.do
*Correspondence: guillermovanderlinde@pucmm.edu.do

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Abstract: This study uses Ajzen's Theory of Planned Behavior (TPB) to examine entrepreneurial intention in Latin American universities. It uses linear regression analysis to assess the impact of close friends, family, other students, the supportive atmosphere, and willingness to engage in entrepreneurial activities. Results show that peer pressure, strong friendships, and family pressures significantly influence an individual's decision to start a business or entrepreneurial pursuit. The study also shows a positive correlation between promoting entrepreneurial activity among students and developing entrepreneurial aspirations. However, the university's environment and culture have a weaker influence. The study suggests that improving entrepreneurial education and skills is necessary to foster strong entrepreneurial inclinations among students.

Keywords: entrepreneurial intention, entrepreneurship education, college environment, social context

1. Introduction

Over the past two decades, entrepreneurship has gained significant prominence worldwide, emerging as a key driver of innovation and economic growth for nations and regions (Audretsch, 2002; Christensen et al., 2002; Mai & Gan, 2007; Majumder, 2021). This phenomenon has been extensively studied from multiple perspectives, including motivation (Mahto & McDowell, 2018; Murnieks et al,2020), barriers to entrepreneurship (Gorji & Rahimian, 2011; Sharma, 2018;2019), entrepreneurial intention (Fayolle & Liñán, 2014; Urban, 2020; Youssef, et al. 2021), and gender differences in entrepreneurship (Dheer, et al., 2019; Kuschel et al., 2020; Sarfaraz, et al., 2014), among other aspects.

Within this body of research, two main lines of inquiry seek to explain the factors that foster entrepreneurship: the individual and the contextual approaches. The individual approach focuses on entrepreneurs' traits, psychological characteristics, skills, and prior experiences (Kobylińska & Martínez Gonzales; Tomczyk et al, .2013). On the other hand, the contextual approach highlights external factors that facilitate or constrain entrepreneurial activity, such as public policies, education, culture, and the business environment (Busenitz et al., 2014; Lee et al., 2011). From this contextual perspective, key drivers of entrepreneurship include institutional frameworks, support programs, and business infrastructure (Ahadi & Kasraie, 2020; Fuller & Pickernell, 2018; Novejarque Civera et al., 2021; Szpilko et al., 2021).

However, much of the literature on entrepreneurial intention has often overlooked the role of external factors, placing greater emphasis on individual characteristics that influence the propensity to start a business.

Nevertheless, research has consistently shown that entrepreneurial intention (EI) is a reliable predictor of entrepreneurial behavior (Fayolle & Liñán, 2014). Since intention is the strongest antecedent of behavior, a comprehensive understanding of the factors that shape EI is essential for assessing entrepreneurial dynamics (Ajzen, 1991; Krueger et al., 2000).

The environment in which entrepreneurial intention develops is crucial, as certain conditions are more conducive to fostering entrepreneurship than others (Novejarque Civera et al., 2021; Suresh & Ramraj, 2012). However, there is still considerable debate in the literature regarding the contextual elements that best explain how external conditions influence entrepreneurial inclinations (Vuong et al., 2020). Recent research has emphasized the significance of business environments, infrastructure, and entrepreneurial policies in creating a favorable entrepreneurial ecosystem (Davari & Farokhmanesh, 2017; Guglielmetti, 2010). Additionally, the role of education in shaping entrepreneurial intention has been widely acknowledged, as it contributes to the formation of positive attitudes toward self-employment (Rahman & Lian, 2011; Van der Sulis, Van Praag, & Vijverberg, 2008). Substantial empirical evidence supports the idea that entrepreneurial education fosters the creation of new businesses and contributes to developing entrepreneurial societies (Gurtner & Soyez, 2016).

From a sociological perspective, globalization has led to an increasing homogenization of cognitive, relational, and behavioral patterns, reinforcing the need to examine entrepreneurial intentions within specific regional contexts and across different population segments (Nowak et al., 2006). This is particularly relevant for Generation Y (individuals born between 1980 and 2000), who are expected to play a crucial role in shaping the future entrepreneurial landscape (Nabi et al., 2010). Among this group, university students represent a key segment, as they have shown significant interest in entrepreneurship and the development of entrepreneurial goals (Gurtner & Soyez, 2016; Utami, 2017).

In this context, the present study aims to analyze the entrepreneurial intentions of university students in Latin America, addressing the gaps and challenges identified in the literature and contributing to the development of the conceptual framework from a contextual perspective.

2. Literature review and hypotheses development

2.1 Entrepreneurial Intention

The literature on entrepreneurial intentions represents a significant achievement in entrepreneurship. However, entrepreneurship theory intersects with social psychology, where integrating these disciplines is beneficial. This convergence is particularly relevant as the concept of entrepreneurial intention aligns with developments in psychological theory, specifically behavioral intention. Ajzen's Theory of Planned Behavior (TPB) is a widely applied framework for predicting and understanding human behavior across various domains (Ajzen, 2020). The theory posits that intentions, influenced by attitudes, subjective norms, and perceived behavioral control, are the primary determinants of behavior (Ajzen, 2015). Entrepreneurial intention is embedded within the broader theoretical framework of planned behavior, which provides a foundational perspective for understanding entrepreneurial decision-making (Ajzen, 1991). Consequently, intention is crucial in the transition from thought to action.

Behavioral intention is fundamental to decision-making, reflecting an individual's deliberate commitment to pursuing a particular action. Entrepreneurial intention, therefore, represents an individual's conscious decision to engage in entrepreneurial activities (Ajzen, 1985; Singh & Onahring, 2019). According to Bird (1988), entrepreneurial intention is a cognitive state that precedes the actual implementation of a business idea. In this context, entrepreneurial intention is the cognitive and motivational precursor to transforming an idea into a tangible product or service.

Entrepreneurial intentions reflect a firm commitment to establishing a new business venture and outline the strategies required for its realization (Farrukh et al., 2018; Fayolle & Liñán, 2014). Moreover, entrepreneurial intention is a key characteristic of individuals who aspire to create new enterprises and contribute to economic growth through innovation and business development (Al-Mamary & Alraja, 2022). Research by Aliyu et al. (2015) underscores the significance of entrepreneurial intention as a catalyst for business growth and expansion, fostering both autonomy and individual creativity in business endeavors. Similarly, Alferaih (2022) posits that entrepreneurial intention is pivotal in shaping career choices, particularly among aspiring entrepreneurs.

A comprehensive understanding of the factors influencing entrepreneurial intentions is essential, as entrepreneurship cannot exist without an initial intention (Elnadi & Gheith, 2021). Therefore, exploring the motivations and determinants that drive individuals to engage in entrepreneurial activities is imperative. Encouraging and nurturing strong entrepreneurial intentions is vital for fostering entrepreneurship at both the individual and societal levels.

2.2 University Context

Entrepreneurship education has increasingly become a priority for universities, policymakers, and scholars (Kuratko, 2005). The growing emphasis on entrepreneurship education is attributed mainly to its impact on economic development and employment generation (Audretsch et al., 2011). Research has demonstrated that entrepreneurship education enhances awareness of entrepreneurial opportunities, attitudes, and intentions (Fayolle & Liñán, 2014; Iizuka & De Moraes, 2014; Liñán et al., 2011; Tkachev & Kolvereid, 1999). These findings suggest that exposure to entrepreneurial education and training plays a crucial role in shaping students' entrepreneurial mindsets and behaviors.

The university environment is an incubator for entrepreneurial activities, facilitating identifying and pursuing business opportunities (Edelman & Yli-Renko, 2010; Urbano & Guerrero, 2013). Universities catalyze entrepreneurial intention by providing students access to resources, mentorship, and experiential learning opportunities. Consequently, universities contribute to the development of future entrepreneurs by fostering an ecosystem that supports business creation and innovation (Johannisson et al., 1999; Wang & Verzat, 2011).

Despite these efforts, many students face barriers to entrepreneurship, including a lack of practical experience, risk aversion, and insufficient preparedness (Awwad & Al-Aseer, 2021). While universities are critical in promoting entrepreneurial careers, they are often criticized for focusing excessively on theoretical knowledge rather than practical applications (Anjum et al., 2022; Anwar et al., 2020). Many institutions have introduced specialized entrepreneurship programs at both undergraduate and graduate levels to bridge this gap.

The term "university environment" refers to the various educational, research, and outreach initiatives supporting entrepreneurship within higher education institutions. Research suggests that students develop their entrepreneurial profiles through engagement in university-sponsored activities (Fayolle & Liñán, 2014). Entrepreneurial education has positively influenced entrepreneurial intentions (Barba-Sánchez et al., 2022), highlighting the importance of integrating entrepreneurship-focused curricula into higher education.

2.3 Family Context

Family background has been identified as a significant factor influencing entrepreneurial intentions. Studies indicate that familial support and exposure to entrepreneurial role models are crucial in shaping individuals' career choices (Farooq et al., 2018). Relational support from family and friends—both moral and financial—can significantly impact an individual's decision to pursue entrepreneurship. The availability of initial capital, often sourced through family connections, is a key determinant of entrepreneurial entry (Ambad & Damit, 2016; Patuelli et al., 2020).

Entrepreneurial performance has been found to correlate with the degree of family support, reinforcing the notion that strong relational networks enhance entrepreneurial success (Farooq et al., 2018; Jena, 2020; Meoli et al., 2020). Motivation is also critical in the entrepreneurial process, as it mediates the relationship between intention and action (Carsrud & Brännback, 2011; Fayolle et al., 2014). Entrepreneurship-related motivation theories can be categorized into "incentive theories," which focus on external rewards, and "necessity theories," which emphasize internal drivers such as personal aspirations and economic necessity (Carsrud & Brännback, 2011; Fayolle et al., 2014).

Given these insights, family background and support emerge as fundamental predictors of entrepreneurial intention. Studies confirm that a strong familial entrepreneurial history enhances individuals' likelihood of pursuing business ventures (Damoah, 2020). Understanding these familial influences is essential for developing policies and programs that support aspiring entrepreneurs.

2.4 Social and Cultural Context

Social and cultural factors significantly influence entrepreneurial intentions. Research has established that cultural values, societal norms, and social acceptance of entrepreneurship impact individuals' willingness to engage in entrepreneurial activities (Guerrero et al., 2016; Lee et al., 2006). Among the key sociocultural determinants are individualism versus collectivism, power distance, and risk aversion (Hofstede, 2001).

Studies suggest that societies emphasizing individualistic values tend to foster higher levels of entrepreneurial activity due to greater social legitimacy and support (Liñán & Fernandez-Serrano, 2014). Conversely, cultural norms discouraging innovation and risk-taking can impede entrepreneurial ambition (Liñán & Chen, 2009; Shinnar et al., 2012). Additionally, risk aversion—the extent to which individuals perceive uncertainty as a threat—negatively correlates with entrepreneurial engagement (Wennekers et al., 2007).

Social context plays a moderating role in shaping entrepreneurial creativity and aspirations. Studies indicate that innovation and entrepreneurial norms are intertwined, yet cultural constraints may limit entrepreneurial potential (Al-Mamary et al., 2020; Bello et al., 2018). Recognizing the interplay between social, cultural, and economic factors is essential for fostering an environment conducive to entrepreneurship.

2.5 Hypothesis Development

Research on why individuals choose to become entrepreneurs should consider potential differences in the sources of family influence, distinguishing between parental influence and other family figures, as well as between nuclear and extended family (Davidsson & Delmar, 2000). Based on this premise, the following hypothesis is proposed:

Hypothesis 1:
Ho The influence of close friends is not positively associated with the development of entrepreneurial intention.
Ha The influence of close friends is positively associated with the development of entrepreneurial intention.

Parents can serve as role models in entrepreneurship (Delmar & Davidsson, 2000), transferring entrepreneurial skills to their children, particularly when they expect them to eventually take over the family business (Westhead, 2003). Whether family bonds are supportive or antagonistic, lenient or restrictive, they represent most individuals' closest and strongest connections. Consequently, family influence is likely to be a decisive factor in shaping decisions and behaviors related to entrepreneurship. A nascent entrepreneur may encounter diverse reactions from acquaintances, friends, and loved ones, but family support—or its absence—plays a particularly significant role (Begley & Tan, 2001). Empirical evidence suggests that encouragement and support from family members, relatives, and friends are associated with entrepreneurial development (Davidsson & Honig, 2003). Based on this, the following hypothesis is formulated:

Hypothesis 2:
Ho. The influence of close family members is negatively associated with the development of entrepreneurial intention.
Ha. The influence of close family members is positively associated with the development of entrepreneurial intention.

Peer influence, understood as an entrepreneurial experience shared among individuals engaged in entrepreneurial activities, also constitutes a relevant factor. Peers, in this context, are defined as individuals within a person's network who are in similar life stages and circumstances, such as classmates (Falck et al., 2012).

Strong evidence suggests that peers can act as role models for entrepreneurship (Falck et al., 2012). While research on the relationship between entrepreneurial intention and peer influence remains limited, several studies have corroborated this link (Falck et al., 2012; Nanda & Sørensen, 2010). Consequently, the following hypothesis is proposed:

Hypothesis 3:
Ho. The influence of fellow students is negatively associated with the development of entrepreneurial intention.
Ha. The influence of fellow students is positively associated with the development of entrepreneurial intention.

According to Rauch and Hulsink (2015), entrepreneurship education positively correlates with entrepreneurial intention. Previous research has examined the relationship between entrepreneurial intention, entrepreneurial behavior, perceived university support, and the need for additional university assistance (Kraaijenbrink et al., 2010). Based on these insights, the following hypothesis is proposed:

Hypothesis 4:
Ho A favorable entrepreneurial climate at the university is negatively associated with the development of entrepreneurial intention.
Ha. A favorable entrepreneurial climate at the university is positively associated with the development of entrepreneurial intention.

Some studies have explored constructivist perspectives emphasizing hands-on experience and practice rather than exclusively formal entrepreneurship education (Löbler, 2006). Research has also investigated the relationship between entrepreneurship education and various factors, such as participation in entrepreneurial activities, opportunity recognition, and risk-taking propensity (Solesvik et al., 2014).

Kraaijenbrink et al. (2010) highlighted the importance of academic support in shaping entrepreneurial intention, a finding further expanded by Saeed and Muffatto (2012), who identified a strong correlation between entrepreneurship education and idea generation, as well as institutional support for business development. Based on these findings, the following hypothesis is proposed:

Hypothesis 5:
Ho The promotion of entrepreneurial activities within the university is negatively associated with the development of entrepreneurial intention.
Ha. The promotion of entrepreneurial activities within the university is positively associated with developing entrepreneurial intention.

Recent studies on the entrepreneurial transformation of universities in the United States, the United Kingdom, Finland, Sweden, and Norway suggest that entrepreneurship programs are shaped by the institutional structure of universities and their integration with the external environment (Foss & Gibson, 2015).

Additionally, previous research has emphasized the relationship between the institutional environment and entrepreneurial activity across various contexts (Valdez & Richardson, 2013; Williams & Vorley, 2015). In this framework, institutional theory (Scott, 2014) considers the university an essential setting for entrepreneurial engagement.

A meta-analysis of 73 studies conducted by Bae et al. (2014) found that entrepreneurship education increases startup intentions. However, other scholars have reported contradictory findings and argue that entrepreneurship courses may sometimes dampen students' entrepreneurial inclinations (Oosterbeek et al., 2010).

More recent research has demonstrated that students who engage in entrepreneurial experiential learning exhibit higher entrepreneurial intention levels (Kassean et al., 2015). Based on these findings, the following hypothesis is proposed:

Hypothesis 6:
Ho The university context inspires students to develop new business ideas and is negatively associated with the development of entrepreneurial intention.
Ha The university context inspires students to develop new business ideas and is positively associated with the development of entrepreneurial intention.

3. Methods

3.1 Data and Sample

This study utilizes data from the 2021 Global University Entrepreneurial Spirit Students' Survey (GUESSS), whose questionnaire has been translated and rigorously validated by entrepreneurship experts. The sixth edition of the survey, corresponding to 2013, comprises 12 sections with question scales ranging from 5 to 7 points. This study focuses exclusively on Latin American participant countries. The dataset includes responses from students who completed the questionnaire in full, with the distribution per country as follows: Argentina (32), Bolivia (68), Brazil (76), Colombia (170), Chile (152), Costa Rica (188), Dominican Republic (214), Ecuador (218), El Salvador (222), Guatemala (320), Honduras (340), Mexico (484), Nicaragua (558), Panama (591), Paraguay (600), Peru (604), and Venezuela (858).

3.2 Measures

3.2.1 *Entrepreneurial Intention*

Entrepreneurial intention is measured using the methodology established by the GUESSS project, which includes the following statements:

"My professional aspiration is to become an entrepreneur."
"I will exert every effort to launch and manage my own company."
"I am willing to do anything to achieve this."
"In the future, I am going to start a business."
"I have seriously considered creating my own company."
"I have a strong desire to start a business someday."

Students rate their agreement with these statements on a Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). The overall measure of entrepreneurial intention is obtained by calculating the mean score across these six items (Liñán & Chen, 2009).

3.2.2 *Social Environment*

According to social cognitive theory (Bandura, 2001), an individual's immediate social environment significantly influences their thoughts and, consequently, their behavior (De Carolis & Saparito, 2006). The collective perception of entrepreneurship as a desirable career path (Begley & Tan, 2001; Busenitz, Gomez, & Spencer, 2000) fosters interest in business creation (Morris, Schindehutte, & Allen, 2005). Social capital

encompasses strong and weak ties (e.g., family members, friends, and classmates) (Woolcock & Narayan, 2000). From a cognitive perspective, these relationships play complementary roles in shaping values, beliefs, and intentions (De Carolis & Saparito, 2006). Fayolle, Basso, and Bouchard (2010) emphasize the importance of considering the interaction between different spheres of social influence when explaining entrepreneurial orientation. Both macro and micro-level social mechanisms promote entrepreneurial attitudes and behaviors (Morris & Schindehutte, 2005). The micro-social environment, consisting of relationships with family, friends, and fellow students, provides legitimacy, guidance, and support (Uphoff, 2000; Hindle, Klyver, & Jennings, 2009).

To assess the perceived influence of the social environment, students respond to the following items:

"If you were to pursue a career as an entrepreneur, how would your immediate family react?"

"If you were to pursue a career as an entrepreneur, how would your friends react?"

"If you were to pursue a career as an entrepreneur, how would your fellow students react?"

3.2.3 University Environment

Another crucial factor is the perceived entrepreneurial orientation of the university environment. Given the potential influence of sample-related and contextual factors, these perceptions must be interpreted cautiously. On a global scale, the average perception score is 4.4, slightly above the neutral midpoint of the 7-point scale (Franke & Lüthje, 2004).

To measure university environment perception, we use the following three items:

"The atmosphere at my university inspires me to develop ideas for new businesses."

"There is a favorable climate for becoming an entrepreneur at my university."

"At my university, students are encouraged to engage in entrepreneurial activities."

These variables collectively provide a comprehensive framework for understanding the factors influencing students' entrepreneurial intentions.

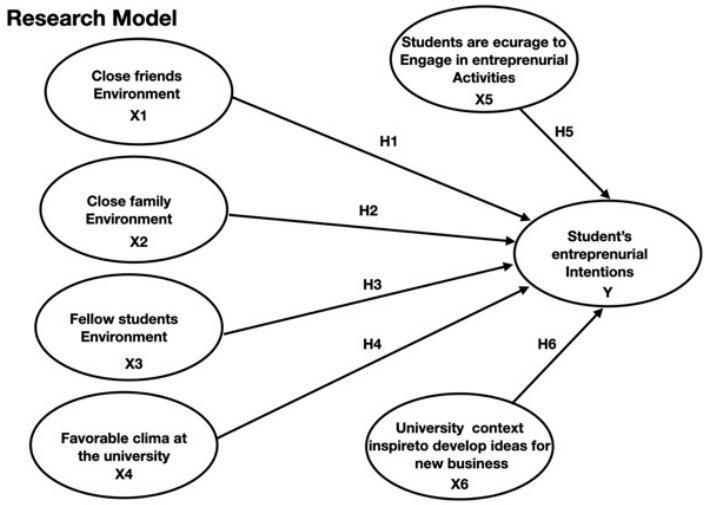

Figure 1 Research Model. The figure explains the research model of how the university and social context impact entrepreneurial intention.

3.3 Using data analysis methods

On the other hand, the SPSS (Statistical Tool for the Social Sciences) statistical package was used to analyze the findings from the questionnaires given to real people. SPSS was used to compute reliability coefficients (Alfa of Cronbach), correlation coefficients, and other metrics in addition to the descriptive statistics for the sample (media and standard deviations, to name a few). After the data was checked to see if the dependent and independent variables showed a linear connection, linear regressions were also put out to explain the primary hypothesis. The component of the error is typically distributed. Multicollinearity is absent. Heteroskedasticity is not present. Hence, the variance of the residual must remain constant for all predicted values.

4. Results

After meeting all requirements (the existence of a linear relationship between the dependent and independent variables, the error component is normally distributed, and there is no multicollinearity and no heteroskedasticity), we use linear regression to prove the hypothesis. Table 1 summarizes the statistical model used in this study. It includes key metrics such as the coefficient of determination (R^2), adjusted R^2, standard error, and significance levels, providing an overview of the model's explanatory power and goodness of fit. The results offer insights into the relationship between the independent and dependent variables, supporting the study's hypotheses and overall analytical framework.

Table 1 Model Summary

Model	R	R Square	Adjusted R Square	Est. Error of the Estimate	R Square Change	F Change	dF1	df2	Sig. f Change
1	.629	.396	.396	8.28360	.396	3349.976	6	30662	.000

Predictors: (Constant) Please indicate how much you agree with the following statement about the university environment (1=not at all, 7= very much). At my university, students are encouraged to engage in entrepreneurial activities., If you would pursue a career as an entrepreneur, how would people in your environment react (1= very negative, 7= very positive)? – Your close family, please indicate the existent to which you agree with the following statement about university environment (1= not at all, 7 = very much). – The atmosphere at my university inspires me to develop new ideas for new business. If you pursue a career as an entrepreneur, how would people in your environment react (1= very negatively – 7 = very positively)? Your fellow students, if you would pursue a career as an entrepreneur, how would people in your environment react (1= very negatively – 7 = very positively)? – Your friend. Please indicate the event to which you agree with the following statement about the university environment ((1=not at all, 7=very much). – There is a favorable climate for becoming an entrepreneur at my university.

Table 2 displays the results of the Analysis of Variance (ANOVA), which assessed the statistical significance of differences among groups. The analysis examines whether the means of the dependent variable vary significantly across different levels of the independent variable(s). The table includes key ANOVA statistics such as the degrees of freedom (df), sum of squares, mean square, F-value, and significance level (p-value). A statistically significant F-value ($p < 0.05$) suggests that at least one group mean differs significantly from the others, warranting further post hoc analysis to identify specific differences.

Table 2. ANOVA

Model	Sum of Square	df	Mean Square	f	Sig.
1 Regression	1379211,225	6	229868,538	3349,976	.000 b
Residual	2103964,172	30662	68,618		
Total	3483175,397	30668			

Dependent Variable: Entrepreneurship Intention

Predictors: (Constant) Please indicate how much you agree with the following statement about the university environment (1=not at all, 7= very much). At my university, students are encouraged to engage in entrepreneurial activities., If you would pursue a career as an entrepreneur, how would people in your environment react (1= very negative, 7= very positive)? – Your close family, please indicate the existent to which you agree with the following statement about university environment (1= not at all, 7 = very much). – The atmosphere at my university inspires me to develop new ideas for new business. If you pursue a career as an entrepreneur, how would people in your environment react (1= very negatively – 7 = very positively)? Your fellow students, if you would pursue a career as an entrepreneur, how would people in your environment react (1= very negatively – 7 = very positively)? – Your friend. Please indicate the event to which you agree with the following statement about the university environment ((1=not at all, 7=very much). – There is a favorable climate for becoming an entrepreneur at my university.

Table 3 presents the estimated coefficients from the regression model, reflecting the relationship between the independent and dependent variables under analysis. Each coefficient represents the marginal impact of a one-unit change in the explanatory variable on the response variable while holding all other variables constant. The model significantly predicted the variables: F 9, 2103964 = 3349, p<.000, as shown by the ANOVA table. The R square for the overall model was 39.9%, with an adjusted R square of 39.6%; the model reports a medium effect.

Additionally, the table includes standard errors, t-values, and significance levels (p-values), allowing for the assessment of the robustness and relevance of each predictor in the model. Statistically significant coefficients

indicate a meaningful influence of the corresponding variable on the dependent variable, whereas coefficients with p-values greater than 0.05 may not be statistically conclusive.

Table 3. Coefficients

	Model	B	Std. Error	Beta	t	Sig.	Zero order	Partial	Part	Tolerance	VIE
	Constant	1.103	0.7		15.702	<0.001					
1	If you would pursue a career as an entrepreneur, how would people in your environment react (1= very negative, 7= very positive)? – Your close friend	0.044	0.009	0.024	5.058	<0.001	0.162	0.029	0.022	0.852	1.174
	If you would pursue a career as an entrepreneur, how would people in your environment react (1= very negative, 7= very positive)? – Your family	0.121	0.007	0.122	17.061	<0.001	0.441	0.097	0.383	0.383	2.614
	If you would pursue a career as an entrepreneur, how would people in your environment react (1= very negative, 7= very positive)? – Your fellow students	0.192	0.006	0.211	30.072	<0.001	0.471	0.169	0.133	0.401	2.494
	Please indicate the extent to which you agree with the following statement about the university environment	-0.096	0.007	-0.073	-14.219	<0.001	0.171	-0.081	-0.063	0.794	1.335

(1=not at all, 7= very much). The atmosphere at my university inspires me to develop new ideas for new business										
The atmosphere at my university inspires me to develop new ideas for new businesses. There is a favorable climate to become an entrepreneur at my university	0.148	0.006	0.198	23.41	<0.001	0.51	0.133	0.104	0.275	3.368
The atmosphere at my university inspires me to develop new ideas for new businesses. At my university, the students are encouraged to engage in entrepreneurial activities.	0.203	0.006	0.281	34.556	<0.001	0.534	0.194	0.153	0.298	3.358

a Dependent variable: Entrepreneurship intention

$Y = B_0 + B_1 x_1 + B_2 x_2 + B_3 x_3 + B_4 x_4 + B_5 x_5 + B_6 x_6$

In the final model, all the independent variables were statistically significant with

Your friends ($t = 5.058$, $p < 0.001$, $b = 0.122$)

Your close family ($t = 5.058$, $p < 0.001$, $b = 0.024$)

Your fellow students ($t = 30.072$, $p < 0.001$, $b = 0.211$)

The favorable climate ($t = 23410$, $p < 0.001$, $b = 0.198$)

Encourage to engage in entrepreneurial activities ($t = 34.556$, $p < 0.001$, $b = 0.231$)

The atmosphere at my university inspires me ($t = -14219$, $p < 0.001$, $b = -0.073$)

The final predictive equation is Y Entrepreneurship intention = 1.103 + 0.122 Your friends + 0.024 Your close family + 0.211 Your fellow students + 0.198 The favorable climate + 0.231 Encourage to engage in entrepreneurial activities - 0.073 The atmosphere at my university inspires me.

4.1 Hypothesis Testing and Interpretation

Table 4 presents the results of the hypothesis testing conducted in this study. The table consists of four columns: (1) Hypothesis Number, which identifies each tested hypothesis; (2) Results**,** indicating whether the hypothesis is supported or not; (3) Values**,** displaying key statistical indicators such as p-values, t-values, or confidence intervals; and (4) Meaning, which provides an interpretation of the findings in the context of the research.

Table 4. Hypothesis testing an interpretation.

	Results	Values	Meaning
Hypothesis 1	The influence of friends on entrepreneurial intention is confirmed	(t = 5.058, p < 0.001, b = 0.122).	This positive coefficient suggests that support from friends moderately encourages entrepreneurial interest. So, the alternative Hypothesis is validated.
Hypothesis 2	The influence of close family also shows a positive association	(t = 5.058, p < 0.001, b = 0.024)	However, the effect is weaker than that of friends and other factors. Close family support plays a minor but positive role. So, the alternative Hypothesis is validated.
Hypothesis 3	Fellow students have a stronger impact	(t = 30.072, p < 0.001, b = 0.211)	indicating that peer influence from other students is significant for fostering entrepreneurial intention. So, the alternative Hypothesis is validated.
Hypothesis 4	A favorable entrepreneurial climate at the university is another strong positive factor	(t = 23410, p < 0.001, b = 0.198)	Implying that an environment conducive to entrepreneurship enhances students' intentions. So, the alternative Hypothesis is validated.
Hypothesis 5	Encouragement to engage in entrepreneurial activities at the university has the highest positive impact	(t = 34.556, p < 0.001, b = 0.231)	This suggests that specific encouragement or incentives are highly effective. So, the alternative Hypothesis is validated.
Hypothesis 6	Interestingly, the "atmosphere at my university inspires me" variable has a negative coefficient	(t = -14219, p < 0.001, b = -0.073).	This negative association might indicate that while the general atmosphere may not inspire entrepreneurial intention, targeted encouragement and peer influence have more substantial impacts. So, the null Hypothesis is validated.

4.2 Overall Conclusion

The analysis confirms that social support and institutional factors significantly impact students' entrepreneurial intentions. Friends, family, and peers play roles, with peer influence (fellow students) showing the most substantial social impact. Institutional support, specifically encouragement, has the most considerable effect. The negative association with the general university atmosphere suggests that targeted support may be more important than the broader campus environment. These results support the importance of active engagement programs and peer influence over general environmental factors.

5. Discussion and conclusions.

This study examines how social and academic environments influence students' intentions to become entrepreneurs in Latin America. According to social cognition theory (Bandura, 2001), an individual's immediate social context significantly shapes their thinking and, ultimately, their behavior (De Carolis & Saparito, 2006). The findings indicate that entrepreneurial intentions are primarily driven by peer pressure and the influence of close friends, whereas the impact of immediate family members is comparatively weaker.

Moreover, the collective perception of entrepreneurship fosters enthusiasm for launching new ventures (Begley & Tan, 2001). Entrepreneurship as a highly desirable career path further reinforces this trend (Busenitz, Gómez, & Spencer, 2000). Social ties, whether strong or weak, among family, friends, and classmates also contribute to entrepreneurial motivation (Woolcock & Narayan, 2000).

On the other hand, while participation in entrepreneurial activities is positively associated with the development of entrepreneurial ambition, the influence of the university environment is less pronounced. As

Franke and Lüthje (2004) noted, the university context plays a role, but its impact is not as strong as social influences.

The study underscores that universities' social and academic environments are key to unlocking entrepreneurial potential. While various studies have reached similar conclusions, methodological differences exist. Despite the generally weak correlation between entrepreneurial education and entrepreneurial intention observed in the literature and this study, regression and correlation analyses confirm a positive relationship between the ambition to start a business and the broader academic and social environment.

The findings suggest enhancing entrepreneurial education and skills to strengthen students' entrepreneurial intentions. Additionally, governments should actively support entrepreneurship education in academic institutions to cultivate a culture of self-reliance and innovation among students.

5.1 implications

The results of this study offer several meaningful implications for educators, university administrators, and policymakers aiming to foster entrepreneurial intention among students. The findings suggest that social and institutional factors are critical in shaping students' interest in entrepreneurship. Here is how these insights could be applied in practice:

1. Enhanced Peer-Led Initiatives and Learning Environments

Peer Influence: Since fellow students have the most substantial positive effect on entrepreneurial intention, universities could leverage this by creating peer-led initiatives. Student entrepreneurship clubs, peer mentorship programs, and collaborative learning spaces could help reinforce entrepreneurial interest through regular peer interaction and support.

Group-Based Projects: Designing course projects requiring teamwork in entrepreneurship-related tasks can enhance peer influence as students observe entrepreneurial problem-solving among their peers.

2. Targeted Institutional Support and Entrepreneurial Programs

Favorable Climate and Direct Encouragement: The positive impact of a favorable entrepreneurial climate and explicit encouragement to engage in entrepreneurship underscores the value of creating a visibly supportive environment. Universities could offer entrepreneurship programs, such as startup incubators, accelerator programs, and business plan competitions, which signal institutional commitment to entrepreneurship.

Access to Resources: Resources such as funding for student startups, workshops on business development, and access to industry networks can further reinforce the perception of a favorable climate and provide tangible support for students.

3. Family and Community Involvement in Entrepreneurial Education

Family Inclusion: Although family influence on entrepreneurial intention was significant but modest, educational institutions could involve families in entrepreneurship education. Family-oriented events, informational sessions, or workshops might help students gain additional family support, bridging family encouragement with university-led initiatives.

4. Strategic Use of the University Atmosphere

Differentiating Atmosphere from Targeted Support: The negative association between the general university atmosphere and entrepreneurial intention suggests that promoting a broad university culture is less effective than specific entrepreneurial encouragement. This insight calls for institutions to focus less on promoting a generalized entrepreneurial culture and more on actionable, visible programs.

Creating Spaces for Entrepreneurship: Universities could set up dedicated “innovation hubs” or co-working spaces where entrepreneurship is visibly practiced and supported. This approach creates a targeted “micro-environment” within the broader university atmosphere, enhancing the immediate relevance of entrepreneurship to students.

5. Policy and Curriculum Development

Policy Implications: Education policymakers could advocate for entrepreneurship as a critical skill and encourage universities to integrate it into their curriculum and student services. Given the substantial influence of encouragement and peer networks, policies that promote interdisciplinary entrepreneurship programs, partnerships with local businesses, and entrepreneurial case studies in the curriculum can enhance entrepreneurial learning.

Curricular Integration: Embedding entrepreneurship modules into non-business disciplines can make entrepreneurship more accessible and increase awareness of the available entrepreneurial support. Such integration may also attract students who might not otherwise seek out entrepreneurship-focused resources.

6. Long-Term Impact on Local Economy and Workforce Development

Entrepreneurship as Workforce Development: By fostering entrepreneurship among students, universities contribute to workforce development, nurturing students who may become future employers. This aligns with broader economic development goals, particularly in communities that could benefit from increased entrepreneurial activity.

Support for Student Start-ups: Universities that successfully foster entrepreneurial intention may witness the growth of student-led start-ups. These startups can have a positive ripple effect, attracting investments, creating jobs, and stimulating local economies.

The implications of this study suggest a shift in educational strategy towards more targeted and actionable support mechanisms. Universities should prioritize hands-on entrepreneurial programs, foster peer networks, and signal their commitment to entrepreneurship. Institutions can play a pivotal role in shaping the next generation of entrepreneurs by tailoring support to student needs and reinforcing peer influence.

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Smart Water Management System in a State University in the Philippines: Challenges and Opportunities

Leoven A. Austria[1], Maricel M. Lacbay[2]

[1] Batangas State University, The Philippines, leoven.austria@g.batstate-u.edu.ph
[2] Batangas State University, The Philippines, maricel.lacbay@g.batstate-u.edu.ph

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Abstract: This study explores the implementation of a Smart Water Management System (SWMS) in a state university in the Philippines to address water resource challenges amid growing student enrollment and infrastructure expansion. Utilizing IoT sensors, data analytics, and machine learning, the proposed SWMS aims to optimize water consumption, detect leaks, and improve overall efficiency. The system integrates real-time monitoring, predictive maintenance, and demand forecasting to enhance sustainability efforts and reduce costs. Key components include smart meters, automated valves, and cloud-based analytics for proactive water management. Despite financial, technical, and institutional challenges, the study highlights the potential benefits of SWMS, including significant water conservation, cost savings, and educational opportunities. Case studies from other universities, such as the University of California, the National University of Singapore, and Arizona State University, demonstrate the effectiveness of innovative water solutions in academic settings. The research underscores the critical role of technology in sustainable resource management and advocates for integrating SWMS as a model for other educational institutions. By leveraging data-driven insights, the institution can improve water efficiency, support environmental initiatives, and serve as a leader in smart campus infrastructure.

Keywords: Smart Water Management Systems (SWMS), IoT and Machine Learning, Sustainability in Education Institutions.

1. Introduction

Smart Water Management is the contemporary method of planning, developing, distributing, and managing water resources using IoT technologies designed to increase transparency and make more reasonable and sustainable usage of these water resources. It applies to multiple sectors: agriculture, farming, industry, services, households, etc. Monitoring water consumption in houses, checking water levels, checking drinking water quality, detecting chemical leakages in rivers around plants, tracking pressure variations along pipes, or checking water quality in aquariums are some of the many valuable applications.

Water management is also crucial in service institutions, including educational facilities. In educational settings, water is essential for several purposes, such as drinking, sanitation, cleaning, and construction activities. Given its important role, it is necessary to optimize water usage to ensure sustainable consumption. Effective water management is a key factor in preserving current water resources and a central topic in advancing sustainability, making it a critical and often debated issue in sustainable development efforts.

The emergence of Smart Water Management Systems (SWMS) presents a transformative solution by integrating advanced technologies such as the Internet of Things (IoT), data analytics, and machine learning.

These systems enable real-time monitoring, predictive maintenance, and automated leak detection, allowing for improved efficiency and conservation efforts. Institutions can optimize water consumption, minimize waste, and reduce operational costs by leveraging IoT-based sensors and cloud computing.

This study explores the potential of implementing an SWMS in a state university in the Philippines. It examines existing water management challenges, proposes a technology-driven framework for improvement, and highlights best practices from global institutions that have successfully integrated smart water solutions. By adopting an SWMS, the university can enhance its sustainability initiatives, reduce resource wastage, and serve as a model for other academic institutions seeking to implement smart infrastructure solutions.

2. Literature Review

Effective water management has become a critical priority in addressing global sustainability challenges, particularly in academic institutions where fluctuating water demand requires innovative solutions. Traditional water management systems often face inefficiencies, leading to excessive water waste, increased operational costs, and environmental concerns. The integration of the Internet of Things (IoT), artificial intelligence (AI), and predictive analytics in Smart Water Management Systems (SWMS) has emerged as a transformative approach to optimizing water resource allocation and ensuring long-term sustainability (Chandler, 2022).

Recent studies highlight how AI-driven analytics and IoT-based monitoring significantly enhance water conservation efforts in smart buildings. Islam et al. (2023) explored how IoT sensors can track water usage in real-time and integrate machine learning to detect leaks and anomalies in water consumption. Their study highlighted that this system can optimize water distribution and reduce wastage by up to 40% through predictive analytics and automation. Moreover, Alshami et al. (2024) comprehensively reviewed how IoT-based systems transform water management. Their study highlights the integration of cloud computing for real-time data processing, enabling remote monitoring of water systems in universities and other institutions. These advancements facilitate automated responses to leaks or excessive water usage.

Beyond IoT and AI, emerging technologies such as blockchain and digital twins are being explored for water management applications. Blockchain ensures secure and transparent data transactions, addressing concerns about data integrity in decentralized water monitoring systems. Similarly, digital twins allow real-time simulation and optimization of water distribution, improving system resilience and efficiency. The study by Naqash et al. (2023) presents a blockchain-based framework for urban water management and leakage detection. The system integrates IoT sensors with blockchain technology to authenticate and securely share real-time water usage and distribution data. The blockchain ensures that all recorded transactions remain tamper-proof, addressing data integrity and transparency issues. Moreover, the study highlights that blockchain can facilitate automated water billing, fraud prevention, and efficient allocation of water resources.

AI and IoT-based SWMS have also been applied in smart city developments. Houssein et al. (2024) examined the role of IoT in smart city infrastructure, including smart water grids. Their study detailed how real-time data processing, AI algorithms, and cloud-based analytics optimize urban water management. The findings align with the potential for academic institutions to implement similar systems for improved water efficiency.

While the advantages of Smart Water Management Systems (SWMS) are well-documented, financial constraints remain a significant challenge for academic institutions. Many universities face high upfront costs associated with deploying Internet of Things (IoT)-based monitoring systems, AI-driven analytics, and necessary infrastructure upgrades, which can deter adoption. This challenge is especially pronounced in resource-constrained regions with limited budget allocations for such technologies. In addition to financial limitations, cybersecurity concerns pose a significant barrier to the adoption of IoT-enabled SWMS. Smart water systems remain vulnerable to cyber threats, compromising sensitive data and operational efficiency. Furthermore, socioeconomic factors, including the digital divide and lack of institutional support, hinder adoption in resource-constrained universities. The ransomware attack in Atlanta in March 2018 and the Ukraine attack in December 2015 are examples of cyber-physical systems. That is why there is a pressing need for mitigating the related risks in using cyber and physical security frameworks (Hassan et al., 2019)

However, despite these hurdles, cost-benefit analyses show promising long-term financial returns. Institutions implementing AI-powered SWMS can recover their costs within 3-5 years, driven by substantial reductions in water bills and maintenance expenses, often 30–40% (Dada, 2023). Additionally, one report in Smart Water Magazine (2025) highlights that AI systems have led to up to a 25% reduction in water usage and a 15% cut in operational costs for industries. Similarly, industries using AI-powered water monitoring have reported savings of up to 20%, and predictive analytics can further reduce water consumption by as much as 15% in regions experiencing water stress (Driving Water Sustainability in the Industry with AI and Automation, 2024)

Beyond immediate cost reductions, AI-powered water management contributes to broader economic and environmental sustainability. According to Gupta et. al. (2020), Smart Water Technology enhances water

conservation and management through real-time monitoring, AI-driven leakage detection, and predictive analytics, reducing water waste and operational costs. In agriculture, smart irrigation systems optimize water use by analyzing soil moisture and weather conditions, cutting water consumption by up to 20% while improving crop yields. Additionally, AI-powered data analysis supports better decision-making, pollution control, and predictive maintenance. However, challenges such as sensor deployment costs, data security, and false alarms in leakage detection still require further research and technological advancements.

Several universities worldwide have successfully implemented smart water conservation technologies, showcasing the tangible benefits of SWMS in higher education institutions. The University of California, Berkeley (UCB), has integrated machine-learning-based predictive water management into its sustainability initiatives. Their 2023 sustainability report highlights a 37% reduction in per capita water consumption from 2007 to 2019 due to AI-powered leak detection and smart irrigation systems (University of California, Berkeley, 2023)

Arizona State University (ASU) has adopted smart irrigation systems that adjust water distribution based on real-time weather conditions. This approach has resulted in substantial savings in landscaping water use, reinforcing the role of technology in efficient water resource management (Arizona State University, n.d.). These case studies prove that implementing SWMS in universities can lead to tangible water conservation outcomes, reduced operational costs, and enhanced environmental sustainability.

In Southeast Asia, the National University of Singapore (NUS**)** has taken an innovative approach by integrating rainwater harvesting, IoT sensors, and machine learning-based analytics into its water conservation strategy. Their Water Efficiency Index has improved by 25% since 2012, demonstrating the effectiveness of SWMS in tropical climates where water demand varies seasonally (National University of Singapore, 2023).

Southeast Asia has seen varying levels of implementation of smart water policy. While Singapore leads in integrating IoT-based water management strategies, Malaysia has also adopted similar policies with government support. Similarly, case studies of Thailand introducing digital technologies for water management in the basin and irrigation project scale can show the processes of development, implementation, and people's capacity for coping (Koontanakulvong, 2023).

In the Philippines, while universities may not yet be at the forefront of implementing Smart Water Management Systems (SWMS), local government units (LGUs) in key cities have made notable strides in adopting smart water solutions that academic institutions could emulate.

For example, Metro Manila, Cebu, and Davao have introduced innovative water management strategies that combine smart technologies and traditional systems like rainwater harvesting. In Davao City, rainwater harvesting systems (RWHS) implementation has been actively promoted, though compliance can be improved. Davao's local ordinances aim to enhance water conservation, yet challenges like low public awareness and insufficient incentives have hindered full compliance (Lumawag, 2018).

In Cebu, Mandaue City has passed the "Stormwater Management Ordinance," which mandates the installation of stormwater management systems, including rainwater tanks, for all new buildings, subdivisions, and commercial establishments. This ordinance seeks to mitigate flooding and enhance water conservation, encouraging the use of harvested rainwater for non-potable purposes like toilet flushing and irrigation. These initiatives are aligned with the broader goal of improving water sustainability in urban settings (Cotejo, 2023).

Predictive analytics enable educational institutions to anticipate water demand fluctuations, ensuring that resources are allocated efficiently. By leveraging historical water consumption data, environmental factors, and academic schedules, universities can prevent shortages and overuse, ultimately contributing to long-term sustainability goals.

3. Materials and Methods

3.1. Study Site and Context

This study focuses on a state university, a rapidly growing educational institution in the Philippines. The campus has experienced significant population growth, increasing the demand for water resources. Water shortages, inefficient distribution, and aging infrastructure persist despite sustainability efforts. The proposed Smart Water Management System (SWMS) aims to address these issues through technology-driven solutions.

3.2. Materials and Technologies Used

The implementation of the SWMS relies on various hardware and software components, including:

IoT Sensors and Smart Meters – Devices for real-time water flow, pressure, and consumption monitoring.

Cloud-Based Data Analytics Platform – A system for processing and analyzing water usage data.

Machine Learning Algorithms – Used for predictive maintenance, anomaly detection, and water demand forecasting.

Automated Valves and Control Systems – Enable remote control of water distribution and leakage prevention.

Network Infrastructure – Wi-Fi and IoT-based communication networks for seamless data transmission.

3.2. Research Design

This study follows a mixed-method approach, integrating quantitative data analysis with qualitative assessments:

3.2.1. Data Collection

Water Usage Data – Historical and real-time water consumption records from smart meters.

Sensor-Based Monitoring – IoT sensors provide continuous readings on water flow, pressure, and quality.

Surveys and Interviews—University administrators, facility managers, and students were surveyed to assess current water management challenges and potential improvements.

3.2.2. Data Analysis

Descriptive Statistics – Used to evaluate trends in water consumption and detect inefficiencies.

Machine Learning Models – Applied to historical water data for leak detection, anomaly identification, and demand forecasting.

Comparative Case Studies – Analyse innovative water management implementations in other universities to identify best practices.

3.3. Limitations and Challenges

This study acknowledges potential constraints, including financial costs, technical integration challenges, and stakeholder adoption. Strategies to address these limitations include phased implementation, stakeholder training, and securing institutional support.

By employing this systematic approach, the study aims to demonstrate how a technology-driven water management solution can enhance sustainability, reduce resource wastage, and serve as a model for other educational institutions.

4. Results and Discussions

The proposed Smart Water Management System (SWMS) for a state university aims to modernize the campus's water management practices by integrating advanced technologies to promote sustainability, optimize resource usage, and reduce costs. At the heart of the system is a centralized control platform that enables real-time monitoring, data analysis, and control across the entire campus. This platform will interface with a network of strategically placed smart meters and IoT-based sensors installed in various buildings, restrooms, laboratories, and outdoor areas, allowing for comprehensive water flow, pressure, and quality tracking. The system’s decentralized sensor network collects data continuously, ensuring that water usage is monitored and irregularities are promptly identified.

Figure 1 presents the conceptual diagram of the university's proposed Smart Water Management System. The system illustrates the flow of water from the pump facility through the treatment plant and reservoir, where a centralized control platform manages real-time monitoring and operations before distribution to university facilities.

Key components of the SWMS include smart meters for real-time water consumption measurement, IoT sensors for detecting leaks and monitoring flow and pressure, and automated valves that can be remotely controlled to isolate sections of the plumbing network when necessary, such as during maintenance or in response to detected leaks. These components are connected to a cloud-based analytics platform that processes the collected data, providing predictive insights for maintenance scheduling, optimizing water usage, and preempting potential system failures.

The SWMS incorporates several water-saving strategies, such as real-time leak detection, which allows for immediate response to minimize water loss, and automated monitoring and reporting that generate daily, weekly, and monthly reports on water consumption trends. These reports help the facility management team set water-saving targets and continuously evaluate the system's performance. The system also supports predictive maintenance by using sensor data to establish maintenance schedules based on equipment conditions, thereby reducing the risk of unexpected failures and improving operational efficiency.

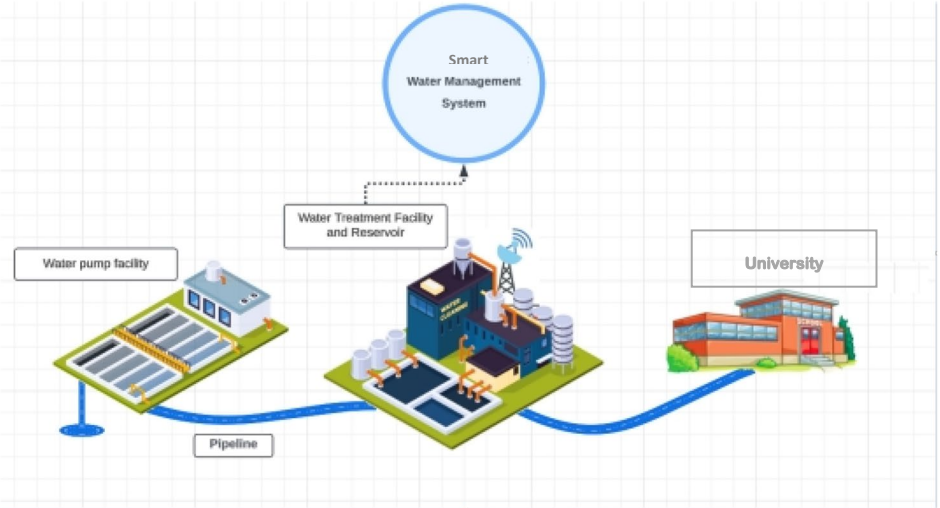

Figure 1. Proposed Smart Water Management System (SWMS)

To integrate the SWMS into the existing campus infrastructure, necessary upgrades to the plumbing system will be made to accommodate smart meters and sensors while ensuring compatibility with current equipment. The system will utilize the campus's existing Wi-Fi network for data transmission, supplemented with a dedicated IoT network to maintain connectivity and system reliability. The anticipated outcomes of this implementation include a 20-30% reduction in water consumption through better monitoring and leak prevention, substantial savings in utility expenses, and a positive environmental impact by promoting sustainable water practices.

The SWMS deployment will be carried out in phases, starting with a feasibility study and detailed assessment of current water management practices. Following this, a pilot implementation in a selected area will serve as a testbed for refining the system's functionality. Once optimized, the system will be rolled out across the entire campus, with provisions for staff training and stakeholder engagement to ensure successful adoption. The final phase will involve continuous monitoring and system improvements based on data-driven insights, ensuring that the university's water management remains efficient and aligned with its sustainability goals.

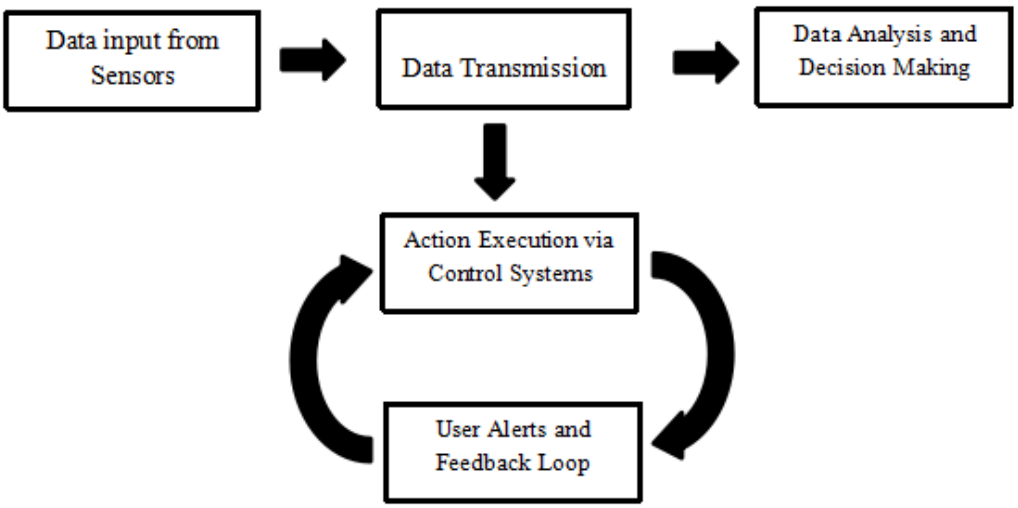

Figure 2. Flow Diagram of the Proposed SWMS

4.1. Predictive Maintenance and Leak Detection Using Machine Learning

Figure 2 shows the operational framework of the proposed smart water management system. The process begins with sensor-based data input, continuously collecting real-time information such as water flow, quality, and pressure. This data is then transmitted to a central platform where it undergoes analysis and decision-making to determine appropriate actions. Once decisions are made, control systems execute the necessary responses, such as adjusting pump activity or redirecting flow. The system also features a user alert and feedback mechanism, which closes the loop by allowing for human oversight and continuous system optimization. This feedback-driven architecture supports proactive management and enhances system responsiveness.

The SWMS collects real-time data from IoT sensors and smart meters installed throughout the campus to monitor water flow, pressure, and usage. By leveraging machine learning algorithms, the system can analyze this data to identify patterns and detect anomalies that could indicate a leak or potential failure.

Smart meters continuously capture data on water flow rates, pressure levels, and consumption patterns at various points across the campus. IoT sensors provide real-time readings on flow and pressure in critical areas, including restrooms, laboratories, and underground pipelines. This raw data is processed, cleaned, and prepared for machine learning analysis.

The system trains the ML model using historical data, such as anomaly detection algorithms or classification models. Supervised learning can be employed if labeled data is available (e.g., previous leaks and non-leak scenarios). Unsupervised learning (like clustering or outlier detection) can be helpful when the system needs to identify anomalies in real-time data without prior labels. The models learn patterns of normal water usage and detect deviations that could indicate a leak, such as sudden flow spikes or pressure drops.

Once trained, the ML model continuously monitors incoming data from the smart meters and sensors. If the system detects a pattern that deviates from the norm, such as an unusual increase in water flow during off-hours or a sudden drop in water pressure, it flags this as a potential leak. The system can differentiate between typical fluctuations (e.g., increased usage during peak hours) and actual anomalies, reducing false alarms. When a potential leak is detected, the system can automatically generate alerts, sending notifications to facility managers via email, SMS, or a mobile app. The SWMS can also trigger automated actions, such as shutting off water in the affected area using remote-controlled valves to prevent further loss.

Table 1 shows the dataset that can be used to train an ML model to detect leaks. The dataset includes:

- Timestamp - The Date and time of the reading.
- Building_ID - Identifier for the building where the sensor is located.
- Flow Rate (liters per minute) - Water flow rate measured by smart meters.
- Pressure (psi) - Water pressure levels.
- Total_Consumption (liters) - Cumulative water consumption for the day.
- Event_Flag - Indicates whether a leak was detected (0 for no leak, 1 for a detected leak).

During regular operation, for most buildings (e.g., BLDG_1, BLDG_3), the flow rate and pressure remain stable, and there are no sudden spikes in water usage. However, when a leak is detected in BLDG_2 and BLDG_4, there are noticeable drops in pressure (from 52 psi to 28 psi) and sudden spikes in flow rate (from 15.0 L/min to 48.0 L/min). These anomalies correlate with Event_Flag = 1, indicating a detected leak. By leveraging such data, the SWMS can predict potential leaks and send alerts, helping the university proactively manage water resources and reduce waste.

Table 1. Sample Dataset for Leak Detection Using Machine Learning

Timestamp	Building_ID	Flow_Rate (L/min)	Pressure (psi)	Total Consumption (L)	Event_Flag
2024-10-01 08:00:00	BLDG_1	25.5	50	800	0
2024-10-01 08:15:00	BLDG_1	28.0	49	825	0
2024-10-01 09:00:00	BLDG_1	26.5	48	850	0
2024-10-01 09:00:00	BLDG_2	15.0	52	500	0
2024-10-01 09:15:00	BLDG_2	45.0	30	560	1
2024-10-01 09:30:00	BLDG_2	48.0	28	600	1
2024-10-01 10:00:00	BLDG_3	20.0	55	900	0
2024-10-01 10:30:00	BLDG_3	22.0	54	950	0
2024-10-01 11:00:00	BLDG_4	60.0	25	1300	1
2024-10-01 11:15:00	BLDG_4	65.0	24	1350	1

The dataset can be used to train a supervised learning model (e.g., a Random Forest or Gradient Boosting model) to classify whether a leak is occurring based on flow rate, pressure, and consumption patterns. Additional features like rolling averages, peak usage hours, and flow rate changes can improve the model's accuracy. Once trained, the model can process incoming data in real time, automatically flagging potential leaks when anomalies are detected.

A study by Coelho et. al (2020) explores a system using a wireless sensor network and autonomous learning algorithms to monitor water distribution systems. It compares machine learning models such as Random Forest, Decision Trees, Neural Networks, and Support Vector Machines (SVM). The study found that the developed system could detect leaks with 75% accuracy in real-world implementations. Similarly, a review paper by Farah et. al. (2024) categorizes traditional and modern leak detection methods, including smart water management and sensor technologies. It evaluates 600 scholarly articles on leak detection over 23 years, highlighting emerging smart water technologies that improve detection efficiency. The study identifies key gaps and suggests future research directions to enhance accuracy and cost-effectiveness. The study emphasizes that advanced ML models and IoT-based real-time monitoring significantly improve water leak detection. However, cost, scalability, and technical challenges remain barriers to widespread adoption.

4.2. Water Demand Forecasting

Water demand forecasting is critical for optimizing resource allocation, ensuring availability during peak times, and minimizing waste during low-demand periods. In this university, where water usage varies depending on academic schedules, special events, and weather conditions, machine learning (ML) models can provide highly accurate and adaptive water demand predictions.

ML models can forecast future water requirements by analyzing historical water usage data, environmental factors, and campus-specific variables. These insights enable efficient water distribution, better maintenance planning, and sustainable resource management.

Water consumption records from smart meters and IoT sensors installed across the campus. Information like weather conditions (temperature, humidity, rainfall), campus schedules, and seasonal trends will be collected, cleaned, normalized, and organized into a time-series format suitable for ML algorithms. Algorithms like ARIMA (Autoregressive Integrated Moving Average) or Prophet are commonly used to model seasonal and temporal water demand patterns. Models such as LSTM (Long Short-Term Memory) networks, which excel in capturing long-term dependencies in time-series data, can account for complex and non-linear patterns in water usage. Combining models like Random Forest or Gradient Boosting with time-series data to improve accuracy by considering external factors (e.g., weather and events).

The system inputs historical and real-time data into the ML model, which analyzes patterns and correlations among variables. The model predicts water demand for specific time intervals (e.g., hourly, daily, or weekly) and forecasts different campus parts. Adjustments are made based on recent trends, ensuring predictions remain accurate as new data becomes available.

The system continuously updates its predictions based on incoming data, adapting to changing conditions, such as unexpected events or weather fluctuations. ML models can simulate various scenarios (e.g., increased usage during campus events or reduced demand during holidays) to help plan resource allocation. Any significant deviation from forecasted demand can trigger alerts, indicating potential leaks, unauthorized usage, or unusual activities.

Key features are derived from the dataset to capture patterns and relationships influencing water usage. These include identifying periods with consistently high water usage (e.g., 8 AM to 5 PM during classes), which helps the ML model understand recurring demand cycles. Additionally, water consumption differs significantly between weekdays (higher demand due to classes and labs) and weekends (lower demand, except during special events). Patterns related to academic semesters or seasons (e.g., summer may have higher demand due to increased temperatures) will also be considered.

Features indicating events like graduation ceremonies, sports meets, or holidays allow the model to anticipate spikes in demand at specific times and locations. The time an event influences water demand (e.g., a 3-hour graduation ceremony might increase usage during and immediately after the event). High temperatures often lead to increased water consumption due to hydration needs and cooling systems. Low humidity can cause more water usage for cooling or cleaning purposes, while high humidity may moderate usage.

Machine learning models are trained using the engineered dataset to predict future water consumption. Two models can be utilized: Time-Series Models and Ensemble Models (e.g., XGBoost). LSTM (Long Short-Term Memory) networks are a deep learning model designed to capture temporal dependencies in sequential data. These models are ideal for predicting water usage trends based on historical patterns, such as peak usage times during weekdays and low usage during weekends. XGBoost (Extreme Gradient Boosting) incorporates historical water

consumption data and external factors like weather and events. It learns how these factors interact and contribute to fluctuations in water demand.

Table 2. Sample Dataset for Water Demand Forecasting

Date	Time	Building ID	Water Consumption (liters)	Temperature (°C)	Humidity	Event Type	Day Type
2024-10-01	08:00	BLDG_1	1200	28	75	Regular Class Sched	Weekday
2024-10-01	12:00	BLDG_1	2000	30	70	Regular Class Sched	Weekday
2024-10-01	16:00	BLDG_1	1800	29	72	Regular Class Sched	Weekday
2024-10-01	20:00	BLDG_1	800	26	80	Canteen Usage	Weekday
2024-10-02	08:00	BLDG_2	1000	27	78	Laboratory Sessions	Weekday
2024-10-02	14:00	BLDG_2	1500	31	65	Laboratory Sessions	Weekday
2024-10-02	19:00	BLDG_2	700	25	85	Canteen Usage	Weekday
2024-10-07	09:00	BLDG_3	800	30	65	Graduation Ceremony	Weekend
2024-10-07	13:00	BLDG_3	2500	33	60	Graduation Ceremony	Weekend
2024-10-0	18:00	BLDG_3	2000	28	70	Graduation Ceremony	Weekday
2024-10-08	10:00	BLDG_4	600	27	75	Regular Class Sched	Weekday
2024-10-08	15:00	BLDG_4	900	30	68	Regular Class Sched	Weekday

Note. The data set includes:
Date and Time - When the water usage data was recorded.
Building_ID - Identifies specific campus buildings (e.g., lecture halls, laboratories, and canteen).
Water_Consumption (liters) - Actual water usage during the period.
Temperature (°C) - Ambient temperature, which may influence water usage.
Humidity (%) - Atmospheric humidity levels can also affect water demand.
Event_Type- Activities or schedules influencing water demand (e.g., Regular Class, Schedule, Canteen Usage, and Graduation Ceremony).
Day_Type- Indicates whether the day is a Weekday or Weekend.

Both models can work together; LSTM focuses on long-term temporal trends, while XGBoost considers contextual and external influences. Shan et. al (2023) proposed a hybrid model integrating Attention-BiLSTM networks with XGBoost for short-term water demand forecasting. This approach was designed to handle complex, non-linear fluctuations in water usage, outperforming traditional models with enhanced predictive accuracy. The study demonstrated that machine learning models, particularly the hybrid Attention-BiLSTM and XGBoost, significantly improve water demand forecasting by capturing complex patterns and incorporating external factors. This approach surpasses traditional forecasting methods, especially in real-world applications where multiple dynamic variables influence demand.

4.3. Challenges in Implementing SWMS

Financial. One of the primary challenges in implementing SWMS on campus is the financial aspect. Implementing innovative water management technologies requires significant investment in infrastructure, training, and public awareness, which can be a hurdle. The initial investment for smart meters, sensors, data

analytics software, and network infrastructure can be high. Olatunde, Adelani, and Sikhakhane (2024) mentioned that investment in SMWS is the most critical challenge in Africa, while in the United States, the challenge often lies in upgrading existing, aging water infrastructure to incorporate new technologies. In addition to upfront costs, ongoing maintenance, software updates, and equipment replacement will incur expenses over time. Allocating resources for long-term operation and support can strain the university's budget, requiring careful financial planning to ensure the system's sustainability.

Technical. Integrating the SWMS with the existing water infrastructure poses significant technical difficulties. The campus's plumbing system may require extensive upgrades to accommodate smart meters, sensors, and automated valves. Ensuring compatibility between the new technology and the legacy infrastructure is essential to prevent disruptions. Additionally, data privacy and security concerns arise due to the system's reliance on IoT devices and cloud-based analytics, making it necessary to implement robust cybersecurity measures. Network connectivity issues can also affect system reliability, especially in areas with weak Wi-Fi signals or limited coverage, potentially impacting data transmission and real-time monitoring.

Institutional. The success of the SWMS relies on the support of the university administration, staff, students, and maintenance personnel. Convincing stakeholders of the new system's benefits may require a cultural shift towards embracing smart technology and sustainability practices. User training is crucial, as facility management staff and other users must understand how to operate the system and respond to alerts. There may also be resistance to change from some staff or students, which could impact the system's effectiveness. Furthermore, regulatory and compliance requirements related to water management must be adhered to, potentially complicating the implementation process.

4.4. Opportunities and Potential Benefits

Adopting smart water solutions addresses many pressing challenges that are facing or resulting from traditional water management systems. In this university, implementing SWMS offers significant opportunities and benefits that can positively impact the campus.

Traditional water management systems are susceptible to many operational issues that may negatively affect efficiency. Smart water technology in an educational institution monitors water systems and enables rapid response to any issues that may affect water supply and quality.

Systems equipped with machine learning capabilities can predict or detect problems early, helping to prevent unexpected downtime and substantial repair costs. For example, water leakages in underground pipes result in severe waste. Smart water solutions enable early leak detection and prompt system repair, helping minimize waste. Efficient water supply systems are more cost-effective in the long run. According to the study of Lawate (2016), SWM can save around 60 billion liters of water, with a 20-30% reduction in usage through low-cost measures. It aims to improve water use efficiency by up to 30%. The return on investment for these systems is generally less than one year due to savings on water bills and operational costs.

Real-time quality monitoring can also help improve public health standards. Water quality monitoring is crucial for maintaining a healthy and safe learning environment for students, staff, and visitors in a school setting. Schools often have water fountains, kitchens, restrooms, and science labs that require clean drinking water for cooking, cleaning, and experiments. Smart water management systems with sensors can continuously monitor water quality metrics like pH, total dissolved solids (TDS), and oxidation-reduction potential (ORP) to detect contamination.

For instance, machine learning algorithms can alert school maintenance teams to take immediate corrective actions if a contaminant increase is detected, perhaps due to a leak introducing pollutants or an issue with the water supply. This could involve shutting down affected water sources, flushing the system, or applying localized treatment to ensure safe drinking water is available.

Such proactive monitoring helps prevent potential health risks, such as gastrointestinal illnesses from waterborne pathogens or chemical exposure from contaminants like lead or pesticides. Additionally, implementing smart water quality monitoring educates students about the importance of environmental health and sustainable practices, fostering a culture of safety and responsibility within the school community.

Smart Water Management Systems also improve consumers' awareness of their consumption. By tracking water consumption in different buildings on campus, the university can identify high-usage areas that may require specific interventions. Moreover, smart meters can signal maintenance teams regarding unusual increases or spikes in consumption, which allows immediate corrective action.

Regarding educational and research opportunities, the data collected from SWMS can be valuable for research projects on water conservation, sustainability, and smart technology applications. Students, engineering, environmental science, and data analytics faculty can utilize this data to conduct real-world studies and publish findings. Projects could focus on developing predictive models for water consumption, assessing the impact of water-saving technologies, or exploring new ways to enhance the efficiency of smart water management.

Similarly, SWMS can be incorporated into the university's curricula, especially in engineering and technology programs. Students can learn about smart infrastructure, IoT applications, data analytics, and sustainable water management as part of their coursework. Hands-on experiences with SWMS will prepare students for future careers in civil engineering, environmental science, and smart technology development. It can also foster innovation by encouraging students to develop new solutions for water-related challenges.

This system helps the campus optimize water usage and is an educational tool. It fosters a culture of environmental responsibility by giving the university community insights into water conservation efforts. Students can learn about the impact of their behaviors on water resources and adopt more sustainable practices, such as reducing shower times, turning off taps when not in use, or using water-efficient appliances in campus facilities.

Ultimately, implementing smart water management in this university can significantly improve water efficiency, contribute to sustainability goals, and serve as a model for other educational institutions that promote sustainable water practices.

5. Conclusions

The proposed Smart Water Management System (SWMS) for a university in the Philippines is a transformative solution designed to address the pressing challenges of water resource management in an academic setting. By integrating advanced technologies such as IoT sensors, machine learning, and real-time monitoring systems, the SWMS aims to optimize water usage, reduce waste, and ensure sustainable practices.

The SWMS can proactively address inefficiencies, prevent disruptions, and adapt to varying campus needs through predictive maintenance, demand forecasting, and leak detection. Despite challenges like financial constraints, technical complexities, and the need for stakeholder collaboration, the opportunities presented by this system, such as cost savings, sustainability, and improved resource allocation, far outweigh the hurdles.

Integrating machine learning into the SWMS further enhances its potential, offering data-driven insights for accurate water demand predictions, anomaly detection, and efficient planning. By aligning with the university's vision for technological innovation and environmental responsibility, the SWMS supports academic excellence and serves as a model for sustainable water management in educational institutions.

This initiative underscores the critical importance of leveraging technology to address real-world challenges. It paves the way for a future where smart resource management becomes a cornerstone of institutional operations.

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