ISSN : 2347-6184

Journal of Indian Institute for Engineering, Management and Science

Volume - 5, Issue I
May 2026

Editor-in-Chief :

Dr. Saket Agarwal

Inspiring Soul

The actual fact of life is,
“To achieve Golden path to success;
one must strive hard from dawn to dusk.”
The crux behind this is,
“The hard work that you put in,
will be recognized as an appreciatioin by honor of success.”

- Mukut Behari Lal

Journal of Indian Institute for Engineering, Management and Science
Volume-5, Issue I, May 2026
ISSN : 2347-6184

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Journal of Indian Institute for Engineering, Management and Science
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Editors - in - Chief Message

Dear All,

It's our immense pleasure to introduce you the Volume-5, Issue-I of Journal of Indian Institute for Engineering, Management and Science (JIIEMS). We would like to extend a very warm welcome to all the readers of JIEMS. In this issue, focus is given to publish original research work that contributes significantly to strengthen the scientific knowledge in area of Engineering, Management, Science & Technology. The key focus would however be the emerging sectors and research which discusses application and usability in societal or consumer context whether individual or industrial. Through this journal, we provide a platform for academicians, research scholars and professionals throughout the world to present latest advancements in different areas. Our goal is to take the journal in a direction where it reflects the multidisciplinary nature and becomes the premier journal that covers all aspects of engineering, management, science & Technology.

The success of any journal is built primarily on four groups of people: the contributors, the reviewers, the associate editors, and the publications staff. For this journal, the contributions have come in not only from the academic community but also from the corporate world. We would like to thank all the contributing authors for providing outstanding research articles on a broad range of topics and we hope that the research featured here sets up many new milestones. We appreciate the efforts put by all the editorial team members, reviewers who have helped us in making this journal a possibility. We have had an overwhelming response from some very eminent editors and researchers globally to support as editorial Team. We look forward to make this endeavor very meaningful. We also thank all the publishing staff members and express my sincere appreciation for the support they have given to JIIEMS.

JIIEMS is currently accepting manuscripts for upcoming issues based on original qualitative or quantitative research, an innovative conceptual framework, or a substantial literature review that opens new areas of inquiry and investigation. Case studies and works of literary analysis are also welcome. It would be definitely a privilege to publish a high quality research article which satisfactorily passes the editorial and peer review protocol. On behalf of the advisory board, we welcome your comments, views and suggestions. I hope to be able to bring about gradual changes in the near future for a successful indexation in the prestigious databases and more importantly for the improvement of the journal.

Please direct any manuscripts, questions or comments to: jiiemsr@gmail.com

Editors-in-chief
JIIEMS

Journal of Indian Institute for Engineering, Management and Science
Volume-5, Issue I, May, 2026
ISSN : 2347-6184

Editors Message

Dear Authors and Readers,

Welcome to the latest edition of Volume-5, Issue-I, Journal of Indian Institute for Engineering and Management Sciences (JIIEMS. As we navigate through the ever-evolving landscape of industrial engineering and management sciences, our commitment to fostering insightful research and facilitating scholarly dialogue remains unwavering. In this issue, we are proud to present a diverse array of articles covering a broad spectrum of topics within our field. From innovative approaches to supply chain optimization to cutting-edge advancements in operations management, each contribution represents a unique perspective and a valuable addition to the collective knowledge base of our discipline.

As editors, we are immensely grateful to the authors whose dedication and expertise have enriched the pages of this journal. Their rigorous research and intellectual curiosity continue to inspire and inform our community, driving progress and innovation in industrial engineering and management sciences. We also extend our heartfelt appreciation to our diligent reviewers, whose constructive feedback and insightful critiques ensure the quality and rigor of the articles we publish. Their commitment to excellence is essential in maintaining the standards of scholarly integrity and advancing the frontiers of knowledge in our field. Finally, we would like to express our gratitude to our readership, whose engagement and support are instrumental in the success of JIIEMS. Your enthusiasm for scholarly inquiry and your commitment to advancing the boundaries of industrial engineering and management sciences are the driving forces behind our continued growth and success. We hope that you find this issue of JIIEMS both informative and inspiring, and we encourage you to join us in our mission to promote excellence in research and scholarship in industrial engineering and management sciences.

Please direct any manuscripts, questions or comments to: jiiemsr@gmail.com

With warm regards,
Sanjeev Kumar Arya
Editor
JIIEMS

Journal of Indian Institute for Engineering, Management and Science (JIIEMS)

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Journal of Indian Institute for Engineering, Management and Science (JIIEMS)

Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

Board Diversity and Sustainability Reporting In Nigerian Listed Consumer Goods Companies

Yahaya Khadijat Adenola[a*], Adinnu Paulina Oluchukwu[b]

[a,b]*Department of Accounting, University of Ilorin, Ilorin, Nigeria*

*Email: yakhadijat@unilorin.edu.ng

ABSTRACT

Corporate complexities, technological innovations, and economic diversification are on the increase and posing serious concerns to business. These global issues are of great concern in driving a modern corporate economy to attain its desired goals. Thus, the need for sustainability reporting through corporate responsibility and accountability. The main objective of this study is to evaluate the effect of corporate board diversity on sustainability reporting in quoted Nigerian consumer goods companies. The study employed both descriptive and inferential statistics using robust least square regression to analyze the data collected. The study revealed that there is a positive significant relationship between diversity of board and sustainability reporting including the three dimensions of economic, social and environmental sustainability reporting. Analysis of the relationship between the attributes of diversity of board studied showed that female board directors and board nationality have a negative insignificant relationship with sustainability reporting, social and environmental reporting and a negative significant relationship with economic sustainability reporting. While the board size has a positive significant influence on sustainability reporting and non-executive directors has no significant relationship with sustainability reporting. The study concluded that board diversity has effect on sustainability reporting of listed Nigerian consumer goods companies. It was therefore, recommended that for a responsive and sustainable business, corporate actors and policy makers should maintain a large and unitary board not falling below standard of Security Exchange Commission and the independence of the board should not be compromised, hence, the non-executive directors' number should be maintained.

Keywords: Board diversity, Board nationality, Board size, Sustainability reporting

1. INTRODUCTION

The long-term success and sustainability of an organization is critical and very crucial to its existence and survival. Thus, a well-composed board contributes to the sustainability of a firm and is key for an effective corporate governance. Board diversity entails the combination of people with different factors that distinguishes them or binds them together. The heterogeneity among board members brings about hypercritical decisions when compared to homogenous board. Corporate governance, and sustainability reporting (SR) is a multifaceted and critical research area especially in terms of economic significance in a diverse country like Nigeria; with a growing, dynamic cultures, and regulatory frameworks.

There is need for an effective corporate governance systems that cater for local characteristics while aligning with global sustainability goals in Nigeria as its practices play a very important role in ensuring that businesses are well-managed, transparent, accountable, contributing to economic stability and growth. Sustainability reporting (SR) which encompasses economic, social and environmental issues is an important part of investment decision-making process especially when investing in companies' sustainability (Tilt et al. 2020; Caporale et al. 2022). The need to evaluate how strong corporate governance and sustainability reporting impact capital flows into businesses is very crucial as any lack of clarity on sustainability reporting practices could lead to information gap thereby affecting investment decisions negatively (Rabaya & Saleh, 2021).

The concept of Sustainability Reporting (SR) by companies is gaining a lot of importance over the past decades. In recent times, there is an increasing interest into accounting and sustainability research especially in the context of non-financial information prepared and presented by companies (Rahman & Alsayegh, 2021). This increase on non-financial information is as a result of the attention and demands from stakeholders; shareholders, customers, employees, suppliers, investors, government, creditors, social and environmental activist groups (Maama & Appiah, 2019) having expectations for businesses to contribute positively to social and environmental well-being.

The traditional financial reporting focuses primarily on financial performance overlooking non-financial aspects such as environmental and social impacts. However, this conventional financial reporting tends to prioritize short-term financial gains and shareholder value over those of other stakeholders, such as employees, customers, communities and the environment which may not align with long term sustainability goals. All stakeholders are important and complements the other, and none to be overlooked. Recent studies in Nigeria, South Africa, and Ghana which centred on corporate governance and financial performance of companies showed significant positive relationships (Coleman &Wu, 2020; Karaye & Buyukkara 2021; Agbata et al; Mensah & Bein, 2023). Scholarly literature on corporate governance and sustainability reporting predominantly carried out in South Africa and Nigeria are emerging (Anazonwu *et al,* 2018; Musa *et al,* 2020; Olayinka, 2021; Modozie & Amahalu, 2021; Osemene *et al,* 2021; Yahaya *et al,* 2022; Chouaibi *et al,* 2022; Bosun-Fakunle *et al,* 2023; Ledi &Ameza-Xemalordzo, 2023 among others), both countries are among the largest developing economies in sub-Sahara Africa. This may be explainable to the mandatory requirement for all listed companies in the Johannesburg Stock Exchange (JSE) to apply the King I, II, III and IV principles to report on sustainability. While in Nigeria, some sector-specific regulations have also played a crucial part in sustainability reporting; the Petroleum Industry Act (PIA) and the Nigerian Sustainability Banking Principles (NSBPs). However, there is still dearth of sustainability reporting and corporate governance mechanisms research (Tilt *et al,* 2020).

Furthermore, previous studies have explained relationship between sustainability reporting and corporate governance mechanisms with the suggestion that board attributes such as board size, gender, non-executive directors' independence, board committees, CEO duality and compensation increase sustainability reporting (Karama et al., 2020; Jamil et al., 2020; Rajakulanajagam 2020; Erin *et al,* 2021; Osemene et al., 2021; Olayinka, 2021; So et al., 2021; Tasim & Khan 2022; Ikpor *et*

al, 2022; Oyekale et al., 2022; Claudya & Raharja, 2023; Helfaya et al., 2023; Uwaifo & Okoh, 2024 among others). Others have shown that board size, independence, institutional pressure have insignificant influence on sustainability reporting (Osemene & Adinnu, 2021; Yahaya et al., 2022; Tasim & Khan, 2022; Agbata et al., 2022; Bosun-Fakunle *et al*, 2023; Abdulrasaq, 2023). This suggests that problem with sustainability reporting and corporate governance still persists especially with regards to measurement parameters. For instance, in the study conducted by Uwaifo & Okoh, (2024), the sustainability reporting variable is based on assigning binary score of one or zero to indicate disclosure or no disclosure reporting respectively. Measurement of sustainability reporting is more than assigning score of zero or one to determine the disclosure index, it involves taking aggregate of the scores to establish the disclosure or reporting index. This study intends to apply composite score of the variables and aggregate them in determining sustainability disclosures. Thus, measurement gap arises and this study intends to fill it by adopting the Global Reporting Initiative (GRI) score index.

Based on the research problem, the following research questions were raised:

- What is the effect of female board directors on sustainability reporting in listed Nigerian consumer goods companies?
- What is the effect of board nationality on sustainability reporting in listed Nigerian consumer goods companies?
- What is the effect of non-executive directors on sustainability reporting in listed Nigerian consumer goods companies?
- What is the effect of board size on sustainability reporting in listed Nigerian consumer goods companies?

This study aims to evaluate the effect of board diversity on sustainability reporting in listed Nigerian consumer goods companies. The specific objectives of the study are to:

- Examine the effect of female board directors on sustainability reporting in listed Nigerian consumer goods companies;
- Evaluate the effect of board nationality on sustainability reporting in listed Nigerian consumer goods companies;
- Determine the effect of non-executive directors on sustainability reporting in listed Nigerian consumer goods companies.
- Determine the effect of board size on sustainability reporting in listed Nigerian consumer goods companies.

Having identified variable gap in the measurement of sustainability reporting, this study is motivated to add to existing literature on sustainability reporting and to the best of our knowledge is a more recent study on the nexus between board diversity and sustainability reporting in Nigeria listed consumer goods companies incorporating gender, board nationality, non-executive directors and board size as components of the independent variable.

2. CONCEPTUAL LITERATURE

1.1. Sustainability Reporting

Overtime, it has been widely acknowledged that sustainability reporting by companies in both developing and developed economies promote transparency and accountability as they enjoy a long-term competitive advantage, improve employee motivation and increase profitability, legitimacy and cost reduction (Nwobu, 2017; Kwakye et al., 2018). Aside from financial statements issued in compliance with mandatory financial requirements, companies issue social and environmental reports, also known as sustainability reporting, aimed at the informational needs of all stakeholders. In the mid-90s, the concept of sustainability reporting emerged putting together environmental, social and economic aspects of the company. This also known as Triple Bottom Line (TBL) is referred to as the three Ps; people, planet and profit. Elkington (2018) stated that Triple Bottom Line (TBL) was based on measured economic prosperity, environmental quality, and social justice. In another definition by Uwuigbe et al., (2018) sustainability reporting is defined as "a tale disseminated by a firm about the environmental, social and societal efforts brought about by its ordinary exercises. Hence, sustainability reporting involves a description of both financial and non-financial activities that happens in an organisation.

Similarly, Mion and Adaui (2020) defined sustainability reporting concept as meeting stakeholders' sustainability information needs relating to economic, environmental and social (EES) impacts of companies' business operations. This definition is buttressed in the study of Merve and Kuzey (2020) which states that sustainability reporting (SR) is a voluntary organisation's activity with two general purposes: to assess the current state of an organisation's economic, environmental and social dimensions, and to communicate an organisation's efforts and sustainability progress to their stakeholders. Invariably, sustainability reporting is not done exclusive of the ordinary activities of the organisation, it is all inclusive and encompassing reporting exercise.

Global Reporting Initiative (GRI) (2022) defined sustainability reporting, disclosure or performance as the process whereby organisations provide information about the economic, environmental and social impact caused by its everyday activities. Sustainability reporting therefore for this study is the practice of measuring, disclosing, and being responsible to all stakeholders (internal and external) for organisational performance on economic, social and environmental issues toward a goal of sustainable development. Disclosing both financial and non-financial activities of the firm provide a more comprehensive report to stakeholders about the financial and sustainability performance of the firm.

1.2. Board Diversity

The concept of board diversity means having a combination of people with different factors that distinguishes them or binds them together. It encompasses an infinite number of dimensions ranging from age to nationality, gender preferences to political preferences, relational skills to task skills, functional background to religious background. A well composed board with different age, class, nationality, educational background, technological knowledge etc. will impact positively on the sustainability of a firm and this matters to good corporate governance practice. There are articles on gender diversity which borders on women participation in decision making process. The presence of women representation at the board will enhance economic, social and environmental performance of any organisation as women are poised more to social activities and care for the environment (Osemene & Adinnu, 2021).

In addition, Garcia-Sanchez et al. (2019) opined that female board commissioners exhibit greater ethical behaviour and commitment in providing higher quality voluntary disclosures making companies with many female board memberships to disclose sustainability information that is more balanced, clear, concise and reliable. Similarly, female gender is less likely to display unethical behavior for the sake more ethical decisions

(Ruiz-Palomino et al., 2021). of the organisation thereby helping the board make a better and Several studies have been carried out on the positive role of women participation in decision making especially on social and environmental sustainability reporting (Pucheta-Martinez et al., 2019; Buallay et al., 2020; Osemene et al., 2021; Modozie & Amahalu 2021; Olayinka 2021, Helfaya et al., 2023 and Bosun- Fakunle et al., 2023). Recent study by Uwaifo & Okoh, (2024) showed a positive but insignificant relationship between gender diversity and sustainability reporting and a positive significant relationship between nationality and sustainability reporting. Few studies showed that there is no impact of female board members on sustainability reporting (Razaq et al., 2023; Orumwense & Osa-Izeko 2023). Despite, the scholarly articles on the influence of gender diversity on sustainability reporting, the need for further studies on other board diversity attributes is very crucial to corporate governance and sustainability reporting discourse. Thus, the essence of this study.

Anazonwu *et al*, (2018) ascertained the influence of corporate board diversity on sustainability reporting on a sample of quoted manufacturing firms in Nigeria using panel data regression. It was found that no significant positive influence of board member nationality exists but for women directors, proportion of non-executive directors and multiple directorships, the relationship was significant. Orumwense & Osa-Izeko (2023) in their study showed that board independence showed a positive but insignificant relationship with environmental sustainability, board size showed a negative significant relationship with environmental sustainability. Also, both gender diversity and board nationality exhibited a negative insignificant relationship with environmental sustainability. Conversely, Salvation *et al*, (2022) in their study on diversity of board and environmental reporting of listed manufacturing companies in Nigeria: the moderating effect of audit committee found that diversity of board has no significant effect on environmental reporting. The study used board size; board independence and directors share ownership as a composite index to proxy diversity of board. Hence, the need for further study on the subject matter.

1.3. Theoretical Review

The agency and stakeholders' theories propounded by Jensen and Meckling (1976) and Johnson (1971) respectively serve as a foundation for this study.

Agency Theory: the proponents suggested a theory of how the governance of a company is based on the conflicts of interest between the shareholders (principal) and the managers (agents). It explores and explains the separation of ownership and management in the organisation as well as the relationship that exist between the principals and the agents within the organisation. Agency theory helps to reduce information asymmetry between principals and agents thereby ensuring business owners and investors have a better investments and long-term sustainability of their resources. As opined in the study of Manita *et al*, (2018), corporate entities that disclose sustainability information represents a tool capable of reducing information asymmetry and mitigating environmental risk, litigation costs and bad reputation. Furthermore, Rasaq et al., (2023) study aligns with agency theory as large board improves sustainability reporting. However, one of the major criticism of agency theory is that it focuses more on shareholders' monetary values and financial outcomes, with less consideration for other potential users of non-financial (economic, environmental, and social) information (Elaigwu et al., 2024). In addition, the theory prioritize short-term gains over long term sustainability goals resulting in decisions that are inimical to the organization's sustainability reporting. Therefore, this study integrates stakeholders' theory to address this gap.

1.4. Stakeholders' Theory

It is based on the conception that a socially responsible firm is one that balances a multiple of interests alongside that of the company owners; that while striving to maximize the wealth of the shareholders who are providers of the firm capital, the firm should also consider the stakes of the employees, suppliers, customers, investors, local communities and the society at large. Johnson (1971) was of the view that agents who are managers of the companies are saddled with the moral duty to consider all stakeholders interest and same should be balanced accordingly. The basic tenet of the stakeholders' theory is the company's management's decisions from time to time, as well as the strategies used to implement these decisions in order to meet the needs of the greatest number of stakeholders in terms of monitoring and non-monitoring considerations through ethical means. Thus, the integration of economic, social and environmental matters by the board of directors through sustainability reporting is an execution of proper corporate reporting from the stakeholders' perspective. In discussing sustainability reporting, several studies have emerged with the argument that sustainability reporting should be anchored on stakeholder theory (Pucheta-Martinez, et al., 2019; Buallay, et al., 2020; Hamad, et al., 2020 and Agbata et al., 2022). These studies purport that business organisations that adopt good corporate governance by satisfying the interest of not only the shareholders but other stakeholders and the entire society have good reputation and perform well. The stakeholders' theory of corporate governance portrays that board of directors in a company owe a duty to major stakeholders, hence a company has a moral duty to consider all stakeholders' interests in their business dealings. =

1.5. Empirical Review

Several studies have been carried on sustainability reporting, financial performance and corporate governance in both developing and developing economies. Studies from emerging economies such as Kumo et al., (2024) who investigated the effect of board attributes, mainly board size, board independence, board gender diversity and board CSR committee on corporate sustainability reporting practices (CSRP), observed that board features such as board size, board overall gender diversity and board CSR committee boast the disclosure of CSRP while board independence negatively affects CSRP. In another study carried out by Pucheta-Martinez et al., (2019) to explore whether board gender diversity specifically women directors representing institutional ownership improves the sustainability development of listed firms by affecting CSR policies. The study showed that women directors representing institutional ownership positively affect CSR policies. In a related study Buallay et al., (2020) examines the relationship between board gender diversity and sustainability reporting. The study revealed that board diversity tends to be higher with banks endowed with low financial leverage and high assets.

Erin et al., (2021) examined the association between corporate governance and sustainability reporting quality of listed firms in Nigeria. It was found that board governance variables (board size, board gender diversity, board expertise and audit committee) are significantly associated with sustainability reporting quality. Similarly, Bosun-Fakunle et al., (2023) investigated the effect of corporate governance on

environmental performance in Zimbabwe. The findings showed that board size, gender diversity and managerial ownership have a positive and significant effect on environmental performance while board independence and institutional ownership have positive and insignificant effects on environmental performance. These studies showed that female participation in board decision making impacts positively on sustainability reporting except for the disparity in the result of Razaq et al. (2023) that examine the effect of corporate governance mechanisms on sustainability reporting of listed non-financial firms in Nigeria with the findings that board size and financial expertise have positive and significant effect on sustainability reporting while board gender diversity has no significant effect on sustainability reporting of listed non-financial firms in Nigeria. This is as a result of different climes of study and methods of unit of analysis.

Osemene et al. (2021) in a comparative study of corporate governance mechanisms and Environmental Accounting Reporting (EAR) in selected African quoted companies, revealed that board committee had a significant influence on EAR in the African countries, board diversity in Kenya and Nigeria, board size in South Africa and Nigeria, board independence in Egypt and Kenya, and institutional ownership in Nigeria, Egypt and South Africa were found to have significant influence on EAR. Musa et al., (2020) investigated the influence of a diverse board on the extent of sustainability reporting in listed industrial goods firms on the Nigeria Stock Exchange. The study revealed that age diversity negatively and significantly affects the extent of sustainability reporting and no evidence was found on the nexus between national diversity, education diversity and sustainability reporting.

Modozie and Amahalu (2021) also examined the effect of board structure on sustainability reporting of listed industrial goods in Nigeria. The study showed that board members shareholding has a significant but negative effect on environmental sustainability reporting, board independence has significant positive effect on environmental sustainability reporting while female board representation and board meeting have a significant effect on environmental sustainability reporting. Conversely, in the study of Yahaya et al. (2022) on the effect of corporate governance on environmental disclosure by listed Nigerian consumer goods firms, it was revealed that the existence of an environmental sustainability committee and board of directors' meetings have a significant positive influence on the extent of environmental information disclosure while board size and board independence does not have a significant influence on the Environmental Disclosure Index of the firms. Further and recent study conducted by Yahaya et al. (2023) on the impact of stakeholders' pressure and information technology governance on the transparency of sustainability reporting of listed Nigerian financial services firms using Random effect regression on 49 firms revealed that stakeholders' pressure and information technology governance have a positive influence on the transparency of the sustainability reporting of the listed Nigerian financial services firms.

From the foregoing reviews, Nigeria and other African countries studies revealed that there is a positive significant relationship between sustainability reporting and board gender diversity, having few studies on board nationality that showed no relationship with sustainability reporting. Thus, giving rise to variable measurement gap, hence, this study measures board diversity by the composite index of female directors, nationality, board size and non-executive directors.

3. METHODOLOGY

3.1. Theoretical Framework

Stakeholders' theory underpins this study as it provides a broader perspective on the relationships between sustainability reporting and board diversity as it aims to explain why and how certain phenomena occur.

3.2. Model Specification

The model was specified to examine the effect of board diversity on sustainability reporting of listed Nigerian consumer goods companies. This study adapted the model of Salvation *et al*, (2022) which is as follows:

$$ER_{it} = \alpha_0 + \beta_1 DOB_{it} + \beta_2 FS_{it} + \beta_3 FA_{it} + \beta_4 ROA_{it} + e_{it} \quad \text{.....3.1}$$

Where:
ER= Environmental reporting; DoB = Diversity-of-Board; FS = Firm size; FA = Firm age
ROA= Return on Assets; t = time period 2002-2019; α_0 = Constant term; e_{it} = Error term,; $\beta 1$ - $\beta 4$ = Coefficient of the variables.
The model adapted was econometrically stated as follows:

$SR_{it} = \alpha_0 + \beta_1 DOB_{it} + \beta_2 PROF_{it} + \beta_3 FS_{it} + e_{it}$ ..... ***Model One***
$ECD_{it} = \alpha_0 + \beta_1 DOB_{it} + \beta_2 PROF_{it} + \beta_3 FS_{it\,t} + e_{it}$..... ***Model Two***
$SOD_{it} = \alpha_0 + \beta_1 DOB_{it} + \beta_2 PROF_{it} + \beta_3 FS_{it} + e_{it}$ ***…Model Three***
$EVND_{it} = \alpha_0 + \beta_1 DOB_{it} + \beta_2 PROF_{it} + \beta_3 FS_{it} + e_{it}$ ..***Model Four***
$SR_{it} = \alpha_0 + \beta_1 FEMD_{it} + \beta_2 BNAT_{it} + \beta_3 BS_{it} + \beta_4 NED_{it} + \beta_5 PROF_{it} + \beta_6 FS_{it} + e_{it}$ ..... ***Model Five***
$ECD_{it} = \alpha_0 + \beta_1 FEMD_{it} + \beta_2 BNAT_{it} + \beta_3 BS_{it} + \beta_4 NED_{it} + \beta_5 PROF_{it} + \beta_6 FS_{it} + e_{it}$.....***Model Six***
$SOD_{it} = \alpha_0 + \beta_1 FEMD_{it} + \beta_2 BNAT_{it} + \beta_3 BS_{it} + \beta_4 NED_{it} + \beta_5 PROF_{it} + \beta_6 FS_{it} + e_{it}$..... ***Model Seven***
$EVND_{it} = \alpha_0 + \beta_1 FEMD_{it} + \beta_2 BNAT_{it} + \beta_3 BS_{it} + \beta_4 NED_{it} + \beta_5 PROF_{it} + \beta_6 FS_{it} + e_{it}$.....***Model Eight***
Where:
SR= Sustainability Reporting; ECD=Economic Dimension; SOD= Social Dimension; EVND= Environmental Dimension; DOB = Diversity-of-Board; FEMD=Female Directors; BNAT=Board Nationality; BS=Board Size; NED=Non-Executive Directors; PROF=Profitability ratio; FIRMSIZE = Firm size; t = time period 2018-2023; α_0 = Constant term; εit = Error term; $\beta 1 - \beta 6$ = Coefficient of the variables.

3.3. Research Design

This study employed the ex-post facto research design as the researcher relied as it permitted the examination of independent variables in retrospect for their possible relationship with the dependent variable. The focus of the study centred on the examination of the relationship between sustainability reporting and board diversity of listed consumer goods companies in Nigeria covering year 2018 to 2023. The periods were chosen due to the currency and availability of data needed for the study. The indicators of board diversity represent the independent variables, while the sustainability reporting index and its various components represent the dependent variable.

3.4. Population Of The Study

The population of this study consist of the twenty-one (21) consumer goods firms listed on the Nigerian Exchange Group (NGX) as of 30th November, 2024. The consumer goods sector was chosen because of its visibility and large market share in addition to its sensitive nature to the environment. This study used data downloaded from each firm's reports (sustainability

reports, annual reports, and websites). In consideration of the sample for the study, a company must have either published annual reports or accounts during the study period that provide substantial support for sustainability performance indicators or a standalone sustainability report of either type (for example, sustainability reports, corporate social responsibility reports, corporate social responsibility progress reports, integrated reports, and corporate environmental reports). Thirteen (13) companies met this consideration thus the sample size.

3.5. Nature And Data Source

The data employed for this study were secondary in nature as they are readily available in the companies' annual reports, websites and publications. Sustainability reporting index represents the dependent variable and was accessed from the annual and sustainability reports of each firm. Prior literature provide that sustainability reporting has three pillars: economic, social, and environmental. Content analysis was used for the quantification of the extent of sustainability reporting in annual reports by companies. The key sustainability performance indicators provided by Global Reporting Initiative (GRI) framework were used. Prior researchers used a disclosure index to study and analyse the sustainability reporting, corporate social responsibility and environmental reporting. This index is applied based on GRI guidelines, in which the KPIs play a central role. These indicators are crucial in the transformation of qualitative information to quantitative measures through content analysis.

Content analysis have been used by previous scholars in the study of sustainability reporting and is a research technique that applies systematic procedures for analysing the content of written medium and converting them into quantitative measures (Dissanayake, 2020; Hamad et al. 2020; Agbata et al. 2022). For this study, the KPIs used in the study of Dissanayake (2020) was applied. The GRI G4 guidelines were introduced in 2013 and are required to be followed by the sustainability reports published after December 2015, in 2018, GRI standards superseded the GRI G4. The GRI - Standards has 88 performance indicators; 13 economic indicators (EC) and 30 environmental indicators (EN) and the social indicator is further divided into four categories; 21 indicators for labour practices and decent work (LA), 11 for human rights (HR), 6 for society (SO) and 7 for product responsibility (PR). (Loprevite et al., 2020).

A Disclosure Index (DI) is used in this study to determine the sustainability reporting level of the sampled firms. In other to trace the sustainability information in all the reports, the FIND option is used. In other to arrive at the value of SRS (dependent variable) for each company sampled, the ratio of the maximum number of points that is obtained by the company to the total expected number of items to be disclosed by the firm is computed.

The independent variables of this study are board diversity indicators. Based on research from Anazonwu et al., (2018) and Salvation et al., (2022), board diversity is measured by the composite index to proxy nationality, board size, women directors and non-executive board members. Aside the independent variables, two other control variables are used. They are profitability ratio and firm size. These variables have been used by prior researchers as determinants of voluntary disclosures and aid control variables in this study.

3.6. Method Of Data Analysis

The descriptive and inferential statistics estimation techniques were used. For data analyses, the technique utilized to analyse the data was panel least square regression.

3.7. Variables Measurement And Definition

The dependent (explained), independent (explanatory), and control variables used to test the hypotheses formulated for the study are presented in table 1

Table.1.Measurement and Description of Dependent and Independent Variables

Symbols	Variable	Measurement	Variable Type	Literature
SR	Sustainability Reporting	Measured by the ratio of the Economic, Social and Environmental indicators scores obtained using the 2020 Global Reporting Initiatives (GRI) standards	Dependent	Claudya & Raharja (2023)
ECD	Economic dimension	Measured by the ratio of economic indicators scores using the 2020 Global Reporting Initiatives (GRI) Standards	Dependent	Claudya & Raharja (2023
SOD	Social dimension	Measured by the ratio of social indicators scores using the 2020 Global Reporting Initiatives (GRI) Standards	Dependent	Claudya & Raharja (2023
ENVD	Environmental dimension	Measured by the ratio of environmental indicators scores using the 2020 Global Reporting Initiatives (GRI) Standards	Dependent	Claudya & Raharja (2023

DOB	Diversity of Board	Measured by the composite index to proxy nationality, board size, women directors and non-executive board members	Independent	Anazonwu et al., 2018; Salvation et al., 2022
FEMD	Female Directors	The proportion of female directors on the board	Independent	Osemene et al., (2021)
BNAT	Board Nationality	This the proportion of foreign directors to total number of directors	Independent	Salvation et al., 2022
BS	Board Size	Total number of directors both executive and non-executive members on the board.	Independent	Osemene et al., (2021)
NED	Non-Executive Directors	Proportion of non-executive directors to total directors on the board.	Independent	Osemene et al., (2021)
PROF	Profitability	Measured as a ratio of net income before tax to shareholder's equity	Control	Osemene et al., (2021)
FRMSIZE	Firm size	Measured by natural log of Total assets	Control	Osemene et al., (2021)

Source: Authors' compilation, (2024).

4. RESULTS AND DISCUSSION OF FINDINGS

The characteristic of the data used for this study is presented Author's computation (2024) (Stata 14)

The descriptive table gives a summary of the test statistics. Sustainability reporting score stood at 0.587, representing 59% of the average score for companies in the consumer goods sector with a minimum score of 34% and maximum score of 74%. The environmental indicator on the average showed 80%, economic indicator 60% and the social indicator 40%. This implies that the consumer goods companies are environmentally friendly and fairly balanced socially. The composite index of diversity of board shows a mean value of 5.22 with a standard deviation of 1.19 that is relatively small compared to the average. The mean score of female directors and board nationality stood at 2.23 and 0.77 respectively with a minimum of 0 and maximum of 5 female directors on the board. The board nationality is about 77% diverse with the presence of foreign nationals. On the average, the board size is 10 having both executive and non-executive board members with a minimum of 6 and maximum of 15 board members. This implies that consumer goods companies in Nigeria are within the threshold of board size as stipulated by Securities and Exchange Commission (SEC) (2011) corporate governance code which stated that public company's board size should not be less than five directors and not above twenty. The non-executive directors have a mean score of 7.76 with a minimum of 3 non-executive directors and a maximum of 14 non-executive directors on the board. This implies that with this average number of 7 non-executive directors, the wealth of their knowledge, expertise and independent judgment will be seen on issues of strategy and performance on the board decisions among which is sustainability reporting.

Table.2.Descriptive statistics

Variable	Obs	Mean	Std.Dev.	Min	Max
SR	78	0.587	0.127	0.340	0.740
ECD	78	0.569	0.183	0.290	0.880
SOD	78	0.427	0.120	0.180	0.600
ENVD	78	0.808	0.165	0.520	1.000
DOB	78	5.224	1.194	2.500	8.250
FEMD	78	2.231	1.194	0.000	5.000
BNAT	78	0.769	0.424	0.000	1.000
BS	78	10.141	2.173	6.000	15.000
NED	78	7.756	2.408	3.000	14.000
PROF	78	0.289	0.781	-2.295	4.323
LFRMSIZE	78	10.943	0.537	9.596	12.040

Clearly, the results from the control variables employed in the analysis shows for profitability an average of 29% profitable firms in the sector with a minimum of ₦2,294,700,000 loss and a maximum of ₦4,322,700,000 profit. The firm size measured by log of total assets showed a mean value of 10.943 having a minimum value of 9.596 and maximum value of 12.04.

4.1. Regression Result

Diagnostic tests are carried out in other to validate regression model. There are certain tests that should be carried out to aid drawing conclusion based on the regression analyses, test of hypotheses and the coefficient estimation accurately. Similarly, certain assumptions must be met to use ordinary least square, among which are test to check for the presence of multicollinearity and heteroscedasticity problem. This study used the Variance Inflation Factor (VIF) to check for multi

collinearity problem and the Breusch-Pagan/Cook Weisberg test for heteroscedasticity problem.

Table.3.Results of Regression Model, Test for Multicollinearity and Heteroscedastic

	MODEL 1			MODEL 2			MODEL 3			MODEL 4		
Variable	coef.	t.stat	p>(t)	coef.	t.stat	p>(t)	coef.	t.stat	p>(t)	coef.	t.stat	p>(t)
Con	1.255	4.150	0.000	1.935	4.550	0.000	0.022	0.080	0.938	2.488	6.440	0.000
DOB	0.059	4.240	0.000**	0.076	3.990	0.000**	0.045	3.460	0.001***	0.068	3.810	0.000***
FEMD												
BNAT												
BS												
NED												
PROF	0.174	1.850	0.069*	0.321	2.420	0.018**	0.171	1.970	0.053	0.921	0.760	0.447
LFRMSIZE	-0.091	-2.900	0.005**	-0.166	-3.760	0.000**	0.015	0.530	0.596	-0.188	-4.700	0.000***
R-SQUARED			0.237			0.267			0.271			0.256
VIF			1.340			1.340			1.340			1.340
Breusch-Pagan			0.001			0.231			0.026			0.012
NO.=obs			78			78			78			78

	MODEL 5			MODEL 6			MODEL 7			MODEL 8		
Variable	coef.	t.stat	p>(t)	coef.	t.stat	p>(t)	coef.	t.stat	p>(t)	coef.	t.stat	p>(t)
Con	0.814	2.850	0.006	0.959	2.980	0.004	-0.216	-0.720	0.472	2.082	5.650	0.000
DOB												
FEMD	-0.011	-0.910	0.365	-0.024	-1.760	0.083	0.002	0.210	0.836	-0.022	-1.450	0.152
BNAT	-0.154	-4.150	0.000**	-0.339	-8.110	0.000**	-0.077	-1.980	0.051**	-0.150	-3.140	0.003***
BS	-0.035	3.100	0.003**	0.033	2.640	0.01**	0.013	1.130	0.264	0.061	4.260	0.000***
NED	0.000	0.020	0.981	0.011	1.040	0.304	0.010	1.020	0.310	-0.016	-1.350	0.182
PROF	0.061	0.650	0.520	0.006	0.060	0.952	0.088	0.900	0.372	0.049	0.400	0.688
LFRMSIZE	-0.041	-1.320	0.192	-0.047	-1.340	0.183	0.447	1.370	0.176	-0.149	-3.710	0.000***
R-SQUARED			0.454			0.664			0.327			0.459
VIF			2.390			2.390			2.390			2.390
Breusch-Pagan			0.001			0.846			0.008			0.003
NO.=obs			78			78			78			78

Authors' computation (2024) (Stata 14)

In checking for presence of multicollinearity problem, 5 or greater bivariate correlation between the predictors indicates multicollinearity presence. From table 3, the VIF results from the models ranges between 1.3 and 2.3, suggesting that multicollinearity is not a problem. Further test to determine a uniform variance and the assumption that the errors be constant, Breusch-Pagan/Cook Weisberg test for heteroscedasticity was conducted. The p-values of models 1, 3, 4, 5, 7 and 8 are less than 0.05, the null hypothesis is rejected with the implication that there is absence of uniform variance and the estimates are biased. Thus, the OLS is not appropriate. To correct this problem, the robust regression is applied. Robust regression is a form of weighted and reweighted least square regression used in any situation where some outliers are found.

Table.4.Robust Regression

	MODEL 1			MODEL 2			MODEL 3			MODEL 4		
Variable	coef.	t.stat	p>(t)	coef.	t.stat	p>(t)	coef.	t.stat	p>(t)	coef.	t.stat	p>(t)
Con	1.271	4.060	0.000	1.945	4.290	0.000	-0.020	-0.080	0.937	2.511	5.920	0.000
DOB	0.057	3.940	0.000**	0.086	4.070	0.000**	0.039	3.340	0.001***	0.067	3.430	0.001***
FEMD												
BNAT												
BS												
NED												
PROF	0.139	1.430	0.158	0.327	2.320	0.023**	0.132	1.690	0.095*	0.078	0.590	0.560
LFRMSIZE	-0.090	-2.770	0.007**	-0.171	-3.630	0.001**	0.025	0.960	0.341	-0.190	-4.310	0.000***
PROB.>F			0.002			0.000			0.000			0.001
NO.=obs			78			78			78			78

	MODEL 5			MODEL 6			MODEL 7			MODEL 8		
Variable	coef.	t.stat	p>(t)	coef.	t.stat	p>(t)	coef.	t.stat	p>(t)	coef.	t.stat	p>(t)
Con	0.800	2.650	0.010	0.910	2.650	0.010	-0.176	-1.310	0.196	2.083	5.110	0.000
DOB												
FEMD	-0.014	-1.070	0.287	-0.026	-1.780	0.08*	-0.008	-1.360	0.178	-0.027	-1.580	0.119
BNAT	-0.148	-3.760	0.000**	-0.342	-7.650	0.000**	-0.049	-2.780	0.007***	-0.153	-2.900	0.005***
BS	0.029	2.490	0.015**	0.031	2.310	0.024**	-0.049	-5.010	0.000***	0.060	3.760	0.000***
NED	0.004	0.390	0.701	0.009	0.840	0.406	0.036	8.330	0.000***	-0.014	-1.100	0.274
PROF	0.048	0.480	0.629	0.023	0.200	0.839	-0.023	-0.510	0.609	0.043	0.320	0.750
LFRMSIZE	-0.037	-1.120	0.269	-0.040	-1.060	0.292	0.063	4.270	0.000***	-0.148	-3.320	0.001***
PROB.>F			0.000			0.000			0.000			0.000
NO.=obs			78			78			78			78

Author's computation 2024 (Stata 14)
Note: the asterisks ***, ** and * indicate significance at the level of 1%, 5% and 10% respectively.

Table 4 shows the relationship between diversity of board and sustainability reporting of quoted Nigeria consumer goods companies. In addition, the result shows the nexus between the three dimensions of sustainability reporting namely economic, social and environmental dimensions and the composite index of diversity of board and the individual attributes of diversity of board. Similarly, the relationship between the control variables and the dependent variables is revealed too. The models are of good fit as the F statistics showed p-value of 0.0000. An examination of the robust least square analysis, models 1, 2, 3, and 4 revealed that the composite index of diversity of board has a positive and significant relationship with sustainability reporting, economic dimension, social dimension and environmental dimension with p-values of 0.000, 0.000, 0.001 and 0.001 respectively at 0.05 significant level. While the individual attributes of board diversity such as female board directors have a negative insignificant relationship with sustainability reporting, social dimension and environmental dimension except for economic dimension. At 0.1 significant level, the female board directors with the p-value of 0.08 shows a negative significant relationship with economic dimension of sustainability reporting. The board nationality revealed a negative significant relationship between sustainability reporting and the various dimensions. Board size revealed a positive significant relationship with sustainability reporting, economic dimension and environmental dimension with p-values of 0.015, 0.024 and 0.000 respectively while it also showed a negative significant relationship with social

dimension with p-value of 0.000. The result of non-executive directors showed that there is no significant relationship between non-executive directors and sustainability reporting, economic dimension and environmental dimension but there is a positive significant relationship with social dimension having p-value of 0.000 < 0.05.

In other to improve the predictability of the independent variables in explaining the relationship with dependent variable, control variables are used. For this study, aside from the profitability and firm size ratios, covid19 was introduced due to the impact this period had on business. There is a positive significant relationship between economic dimension and profitability with a p-value of 0.023 at 0.05 degree of freedom. The p-values of 0.158, 0.095, 0.560, 0.629, 0.839, -0.609 and 0.750 shows that there is no significant relationship between profitability and sustainability reporting, social dimension and environmental dimension. The results of log of total assets showed that there is a negative significant relationship between firm size and sustainability reporting, economic and environmental dimension but no significant relationship with social dimension. Model 7 showed that there is a positive significant relationship between firm size and social dimension. The control variable of covid19 showed no relationship with sustainability reporting and the various dimensions.

5. DISCUSSION OF FINDINGS

In aligning with agency theory, Rasaq et al. (2023) posits that large board improves sustainability reporting. Similarly, several scholars have opined in their studies that diverse board influence long term decisions of the organisation (Salvation et al. 2022; Orumwense & Osa-Izeko 2023; Rasaq et al. 2023 and Uwaifo & Okoh 2024) among others. From the result of the robust regression, the positive significant relationship between diversity of board and sustainability reporting and the three dimensions implies that a unit increase in diversity of board will result to 5.7, 8.6, 3.9 and 6.7 unit increase in sustainability reporting, economic, social and environmental dimensions respectively and vice versa. This result does not align with that of Salvation *et al,* (2022) but aligns with the study of Anazonwu *et al,* (2018).

A further analysis on the relationship between sustainability reporting and the three dimensions with the individual attributes of diversity of board revealed that female board directors has a negative insignificant relationship with a sustainability reporting, social dimension and environmental dimension except for economic dimension. This is at variance with Modozie & Amahalu (2021) result that posits a significant effect of female board directors on environmental sustainability reporting. At 0.1 significant level, the female board directors with the p-value of 0.08 shows a negative significant relationship with economic dimension of sustainability reporting. This implies that a unit increase in female directors on the board will lead to 1.4, 0.8 and 2.7 unit decrease in sustainability reporting, social dimension and environmental dimension respectively and vice versa. This is at variance with the study of Olayinka (2021) where the representation of female directors on the board has positive significant effect on economic sustainability reporting. While for economic dimension, a unit increase in female directors leads to 2.6 unit decrease in economic dimension and vice versa.

The implication of board nationality from the analysis is that for every one unit increase on board nationality, there is a 14.8, 32.2, 4.9 and 15.3 unit decrease in sustainability reporting and economic, social and environmental dimensions of sustainability reporting and vice versa. This is in consonance with the study of Anazonwu *et al,* (2018); Musa et al. (2020) which found no evidence on the nexus between national diversity and sustainability reporting. Board size shows a positive significant relationship with sustainability reporting, economic and environmental dimensions except for social dimension. The result implied that for a unit increase in board size, there is a 2.9, 3.1 and 6 increase in sustainability reporting, economic and environmental dimensions. The result is in tandem with the study of Rajakulanajagam (2020); Erin *et al,* (2021); Olayinka (2022); Claudya & Raharja (2023); Bosun-Fakunle *et al,* (2023). Board size also showed negative significant relationship with social dimension of sustainability. That for every unit increase in board size, leads to a 4.9% decrease in social dimension and vice versa. This is in consonance with the study of Osemene & Adinnu, (2021); Kumo *et al,* (2024) but at variance with Yahaya *et al,* (2022).

Non-executive directors' presence at the board influence strategic decisions. There is no significant relationship between non-executive directors and sustainability reporting, economic dimension and environmental dimension but there is a positive significant relationship with social dimension having p-value of 0.000 < 0.05. this implies that a unit increase in non-executive directors leads to 3.6 unit increase in social dimension of sustainability reporting and vice versa. This is at variance with the result of Rajakulanajagam (2020); Modozie & Amahalu (2021) that revealed board in independence has significant positive effect on environmental sustainability reporting.

The implication of the result of profitability ratio that shows a positive significant relationship exist with economic sustainability reporting is that a unit increase in the returns on capital employed will lead to 2.3 unit increase in economic sustainability reporting. Also, the implication of no significant relationship between profitability ratio and sustainability reporting, social and environmental dimension shows that an increase or decrease in the returns on capital employed does not affect sustainability reporting. This is same with firm size which showed negative significant relationship with sustainability reporting, economic and environmental dimensions except for social dimension that showed no significant relationship. Thus, no influence of firm size on sustainability reporting. This is at variance with the study of Adekanmi (2022); Yahaya *et al,* (2022).

6. CONCLUSION AND RECOMMENDATIONS

The study determined the relationship between diversity of board and sustainability reporting and the dimensions of sustainability reporting in Nigeria quoted consumer goods companies. It was revealed in the foregoing analysis that there is a positive significant relationship between sustainability reporting and diversity of board. Furthermore, female board directors have negative insignificant relationship with sustainability, social and environmental sustainability reporting and a negative significant relationship with economic sustainability reporting. Similarly, board nationality shows a negative significant relationship on sustainability reporting, economic, social and environmental sustainability reporting. Consequently, board size shows a positive significant relationship with sustainability reporting, economic and environmental sustainability reporting and no significant relationship with social sustainability reporting. While non-

executive directors revealed no significant relationship with sustainability reporting, economic and environmental sustainability reporting but positive significant relationship with social dimension.

The stakeholders' and agency theories are upheld for this study as the diversity of board especially as regard board size have effect on the sustainability decisions. Based on the findings of this study, it was recommended that board size stipulated by Securities and Exchange Commission should be upheld and adhered to by companies. That female directors should be increased on the board as some companies do not have their presence on the board, same for board nationality that has negative relationship too. Also the independence of the board should not be compromised, hence, the non-executive directors' number should be maintained in other to foster objective input in sustainability reporting.

Finally, there is need to expand this study to include more sectors in the Nigerian economy as this study is limited to quoted consumer goods companies. Also, further study could be extended to small and medium scale industries.

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Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

Overcoming Technological and Institutional Barriers to Blended Learning Adoption in Teacher Training: A Case Study of Kwara State College of Education Oro

Alabelapo K. Akogun[a*], Muhinat B. Bello[b]

[a]*Department of Educational Foundations Kwara State College of Education Oro, Nigeria*
[b]*Department of Social Sciences Faculty of Education University of Ilorin, Nigeria*

*Email: bello.mb@unilorin.edu.ng

ABSTRACT

This study investigates the technological and institutional barriers to blended learning adoption at Kwara State College of Education Oro, employing descriptive survey res earch of a mixed design. A sample of 641 and 90 participants, comprising students and lecturers, was selected using simple random sampling. Data were collected through structured and unstructured questionnaires administered via Google Forms, focusing on assessing technological constraints, institutional policies, and digital literacy levels. Findings revealed significant barriers, including inadequate ICT infrastructure, insufficient digital literacy among educators and students, and inconsistent power supply. Recommendations include establishing a dedicated blended learning committee, developing clear institutional policies, and enhancing digital literacy training. The study concludes that addressing these barriers is crucial for successfully implementing blended learning, ultimately improving educational outcomes and preparing future educators for modern classrooms. By fostering a supportive environment, Kwara State College of Education Oro can enhance the adoption of blended learning methodologies.

Keywords ***Technological barriers, Institutional barriers, blended learning, personalized learning and Teacher training***

1. INTRODUCTION

The integration of information and communication technology (ICT) in education has significantly reshaped teaching and learning processes worldwide. One of the most notable innovations is blended learning, which combines traditional face-to-face instruction with online learning activities. This approach is increasingly recognized for its potential to improve educational outcomes, increase access to resources, and accommodate diverse learning styles (Graham, 2013). Despite its numerous benefits, the adoption of blended learning in teacher training institutions, particularly in developing countries like Nigeria, faces significant technological and institutional challenges. This study focuses on these challenges within the context of Kwara State College of Education Oro, a key institution responsible for preparing future educators. Blended learning is defined as a pedagogical approach that strategically combines in-person classroom experiences with online learning activities to create a more flexible and engaging learning environment (Bonk & Graham, 2012). In the context of teacher training, blended learning offers several advantages, including the development of digital literacy skills, access to a broader range of instructional materials, and opportunities for personalized learning (Owston, 2013). However, the successful implementation of blended learning in teacher training institutions hinges on the ability to overcome various technological and institutional barriers.

Technological constraints are among the most significant challenges to blended learning adoption in teacher training institutions in Nigeria. Adeoye and Adanikin (2019) identified several technological barriers, including inadequate ICT infrastructure, unreliable internet connectivity, and limited access to digital devices. These challenges are particularly pronounced in rural areas, where many teacher training colleges are located. Kwara State College of Education Oro, situated in a rural part of Kwara State, exemplifies these challenges. The institution struggles with inconsistent electricity supply, which hampers the use of technology in teaching and learning. Additionally, the college's limited access to high-speed internet and modern digital devices further complicates the integration of online learning components into the curriculum.

In addition to technological constraints, institutional barriers also play a critical role in hindering the adoption of blended learning. Institutional support is essential for the successful implementation of blended learning, as it requires clear policies, adequate funding, and a commitment to ongoing professional development (Sangrà &Bates, 2011). However, many teacher training institutions in Nigeria, including Kwara State College of Education Oro, lack the necessary institutional framework to support blended learning. For instance, there is often an absence of dedicated e-learning units or departments responsible for overseeing the implementation and management of blended learning initiatives. Furthermore, insufficient budget allocation for ICT resources and the lack of clear guidelines for blended learning delivery are significant impediments.

Resistance to change is another institutional barrier that affects the adoption of blended learning in teacher training. In the study of (Fullan, 2015) it was posits that educational reforms, including the integration of ICT, often encounter resistance from educators who are accustomed to traditional teaching methods. At Kwara State College of Education Oro, this resistance may be driven by several factors, including a lack of understanding of the benefits of blended learning, concerns about the increased workload associated with online teaching, and fear of obsolescence among educators. Overcoming this resistance requires a comprehensive change management strategy that includes awareness-raising, capacity-building, and incentives for adopting innovative teaching practices.

Moreover, the socio-economic context of the students at Kwara State College of Education Oro must be considered when discussing the barriers to blended learning adoption. The findings of (Olaniyi, 2020) highlighted that many students in Nigerian teacher training institutions come from low-income backgrounds and may lack access to the necessary technology for participating in online learning activities. This digital divide exacerbates existing educational inequalities and limits the effectiveness of blended learning as a tool for enhancing educational outcomes. Addressing this issue requires targeted interventions, such as providing affordable access to digital devices and internet connectivity, as well as offering financial support to economically disadvantaged students.

Despite these challenges, there is a growing recognition of the potential benefits of blended learning in teacher training. As noted in the work of (Graham 2013), blended learning can enhance student engagement, improve learning outcomes, and better prepare future educators for the demands of modern classrooms. In the specific context of Kwara State College of Education Oro, the adoption of blended learning could significantly contribute to the professional development of teachers who are proficient in using ICT in their teaching. This, in turn, would improve the overall quality of education in the region, particularly in rural areas where access to quality educational resources is often limited.

To overcome the technological and institutional barriers to blended learning adoption at Kwara State College of Education Oro, it is essential to adopt a multi-faceted approach. This approach should include investment in ICT infrastructure, continuous professional development for educators, and the establishment of supportive institutional policies. Specifically, there is a need to improve access to reliable electricity, high-speed internet, and modern digital devices. Additionally, the college should establish a dedicated e-learning unit responsible for coordinating blended learning initiatives and provide clear guidelines for blended learning delivery. Capacity-building programs focused on digital literacy and the pedagogical use of ICT should also be prioritized to ensure that educators are equipped with the necessary skills to effectively implement blended learning.

Furthermore, addressing the digital divide among students by ensuring access to digital devices and internet connectivity is essential for the success of blended learning. Kwara State College of Education Oro can facilitate this by implementing initiatives that provide affordable technology and financial support, such as scholarships, to economically disadvantaged students. By overcoming technological and institutional challenges, the college can foster an environment conducive to effective blended learning. This approach will enhance teacher education in Nigeria, leading to a more effective and responsive training system.

2. STATEMENT OF THE PROBLEMS

Blended learning is recognized as a powerful tool for improving education by combining traditional and digital instructional methods. The study of (Garrison & Vaughan 2008) highlighted its potential to increase student engagement and enhance learning outcomes. In the context of teacher training, blended learning is particularly valuable as it equips future educators with the digital skills necessary for modern classrooms (Graham, 2013). However, despite its benefits, the adoption of blended learning in Nigerian teacher training institutions, especially in rural areas, faces significant challenges.

Research by (Adeoye & Adanikin, 2019) pointed out the technological barriers such as inadequate ICT infrastructure and unreliable internet connectivity, which are prevalent in Nigerian educational institutions. In the findings of (Sangrà & Bates, 2011) emphasized that institutional support, including clear policies and adequate funding, is crucial for the successful implementation of blended learning. Additionally, (Evarest & Laura, 2011) noted the digital literacy gap among educators and students as a major obstacle to blended learning adoption in Nigeria. Despite these studies, there is a lack of research focused on rural teacher training institutions like Kwara State College of Education Oro. Existing literature primarily addresses challenges in urban or better-resourced contexts, leaving a gap in understanding how these barriers specifically affect rural institutions. This study seeks to fill this gap by providing a detailed analysis of the technological and institutional barriers to blended learning adoption at Kwara State College of Education Oro. By addressing these unique challenges, the study aims to contribute to more effective strategies for implementing blended learning in rural teacher training institutions across Nigeria.

Purpose of the Study: The study investigated the barriers to adopting blended learning, from technological constraints and institutional policies. Specifically, the study examined:

- assess the technological constraints affecting the adoption of blended learning at Kwara State College of Education Oro.
- evaluate the impact of institutional policies on blended learning adoption at Kwara State College of Education Oro.
- analyze the level of digital literacy among educators and students at Kwara State College of Education Oro.
- develop and propose practical strategies for overcoming identified technological and institutional barriers to blended learning adoption at Kwara State College of Education Oro

Research Questions: The following research questions guided this study:

- What are the key technological constraints affecting the adoption of blended learning at Kwara State College of Education Oro?
- How do current institutional policies at Kwara State College of Education Oro impact the adoption of blended learning?
- What is the current level of digital literacy among educators and students at Kwara State College of Education Oro?
- What practical strategies can be developed and proposed to overcome the technological and institutional barriers to blended learning adoption at Kwara State College of Education Oro?

3. THEORETICAL FRAMEWORK

The theoretical framework for this study is underpinned by the Technology Acceptance Model (TAM) and Institutional Theory, which together provide a comprehensive lens through which to analyze the barriers to blended learning adoption at Kwara State College of Education Oro. The TAM, as proposed by (Davis, 1989), focuses on the individual's perceptions—specifically, the perceived usefulness and ease of use of technology—both of which are critical in determining the likelihood of adopting blended learning. This model is instrumental in understanding how technological constraints, such as inadequate infrastructure and digital literacy, might influence educators' and students' acceptance of blended learning tools. Simultaneously, Institutional Theory sheds light on the broader organizational and policy-related factors that impact adoption. It examines how normative, coercive, and mimetic pressures within the institution either facilitate or impede the integration of blended learning into the curriculum (Olaniyi, 2020). The absence of supportive policies or resistance to change within the institution can significantly hinder adoption efforts.

By synthesizing these two frameworks, the study is well-positioned to explore both the individual and institutional

barriers to blended learning, offering a nuanced understanding of the challenges and paving the way for targeted interventions to enhance adoption within the college.

4. METHODOLOGY

his study employs descriptive survey research of mixed design to investigate the technological and institutional barriers to blended learning adoption at Kwara State College of Education Oro. The descriptive survey design is appropriate for this study as it allows for the collection of quantitative and qualitative data that can describe the current state of blended learning adoption identify the challenges faced by educators and students and suggest possible ways out (Sambo, 2008, p. 54).

The population for this study consists of 2,871 comprising both students and lecturers at Kwara State College of Education Oro. From this population, a sample size of 641 participants for quantitative and 90 participants for the qualitative study was selected, including both students and lecturers. This sample provides a representative overview of the college community, ensuring the findings are generalisable to the larger population. This is in line with the Research Advisors' (2006) sample size table, which analysed and concluded that in a population of 2,500 – 3,500 at a confidence level of 95%, and a margin of error of 3.5 a sample size of 641 respondents could be appropriately sampled. A simple random sampling technique was used to select the 641 participants. The population will be divided into two strata: students and lecturers. Proportional sampling will be employed to ensure that the number of participants from each stratum reflects their proportion in the total population. This approach ensures that both groups are adequately represented in the study.

The primary instrument for data collection was a structured questionnaire administered through Google Forms and an unstructured questionnaire, with a psychometric property was content validity and 0.82 and 0.74. The questionnaire was divided into two sections, structured and unstructured on the aims of the study. The collected data was analyzed using both descriptive and qualitative statistical tools of Atlas. ti (thematic analysis). Descriptive statistics, including frequencies, percentages and means. The data was analyzed using Statistical Package for the Social Sciences (SPSS) software.

5. RESULT

The research questions were answered in qualitative and quantitative approaches. A descriptive statistical tool of percentage, mean and thematic analysis of the analysis was presented in tables and charts, making it used to answer the qualitative part. The results are presented as follows:

Research question 1: What are the key technological constraints affecting the adoption of blended learning at Kwara State College of Education Oro?
The is presented in a graphical representation:

Figure 1; reveals mean table indicates that, on average, 92.2% of the 641 respondents at Kwara State College of Education Oro identified the listed technological barriers as significant obstacles to adopting blended teaching and learning. This high percentage demonstrates a strong consensus among respondents regarding the impact of these barriers. With a mean frequency of 591.5, it is evident that a substantial number of respondents consistently recognized each barrier as a hindrance to the successful implementation of blended learning. This suggests that the challenges, such as inadequate internet connectivity, inconsistent power supply, and high costs of technology, are pervasive and widely acknowledged within the institution. The close range of agreement across different barriers (89% to 96%) further emphasizes the uniformity of opinion among the respondents, indicating that no single barrier stands out as significantly less important than others. Instead, these technological barriers collectively pose a considerable challenge to the adoption of blended learning at the institution. This widespread recognition highlights the need for comprehensive strategies to address these issues to facilitate the effective integration of blended teaching and learning methods.

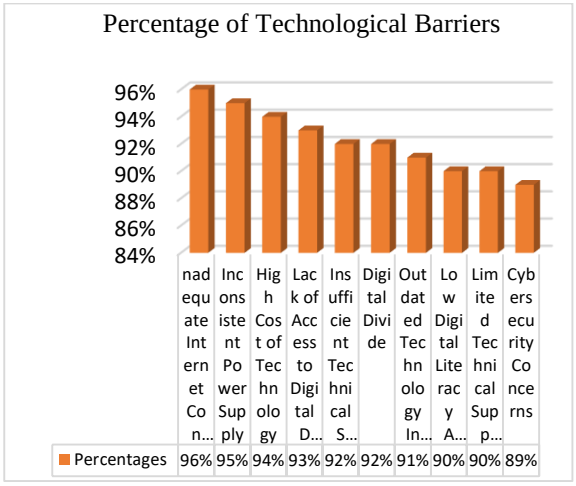

Figure.1. % of Technological Barriers Mean % 92.2%

Research question 2: How do current institutional policies at Kwara State College of Education Oro impact the adoption of blended learning?

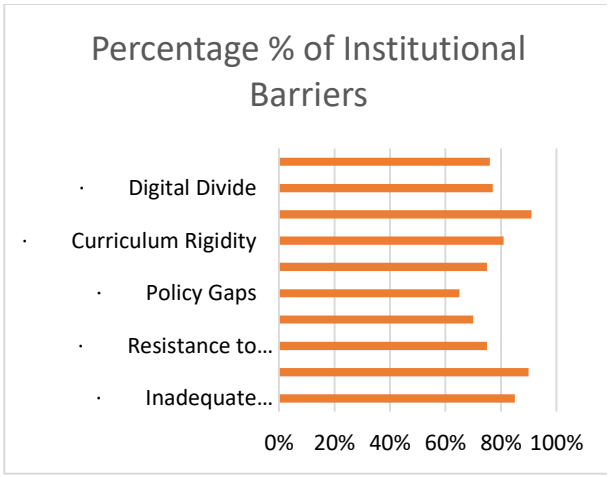

Figure.2.Institutional Barriers Mean =77.9%

Figure 2, revealed the mean percentage of agreement across all identified institutional barriers to the adoption of blended teaching and learning at the College of Education Oro is approximately 77.9%. This indicates that, on average, a strong majority of respondents recognize these barriers as significant challenges to the effective implementation of blended learning. The high mean percentage underscores the pervasive nature of these obstacles, suggesting that comprehensive strategies are required to address them effectively. Overall, the data indicates that a wide range of institutional barriers are recognized by the respondents, with assessment, funding, infrastructure, and curriculum issues being the most prominent. Addressing these

barriers will be essential for the successful implementation of blended learning at the college.

Research question 3: What is the current level of digital literacy among educators and students at Kwara State College of Education Oro? This is presented in the figure three :

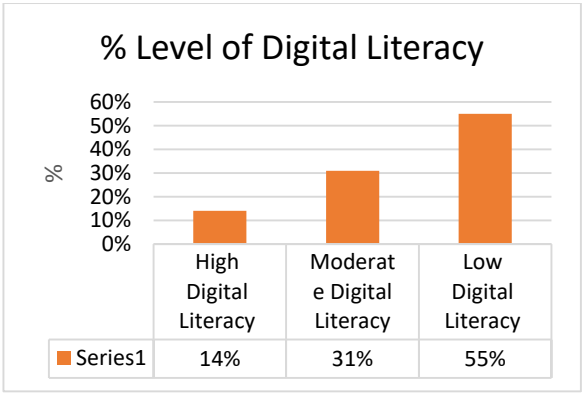

Figure 3 Percentage Level of Digital Literacy

Figure 3: revealed that 55% of respondents have low digital literacy, indicating widespread difficulty with basic digital skills. Only 14% have high digital literacy, showing that very few are proficient with digital tools. The remaining 31% have moderate digital literacy, capable of basic tasks but lacking advanced skills. This highlights an urgent need to improve digital literacy to support effective blended learning and digital initiatives at the college.

Research question 4: What practical strategies to overcome the technological and institutional barriers to blended learning adoption at Kwara State College of Education Oro?

This was presented in a qualitative form in Figure 4 and Table 1 as follows:

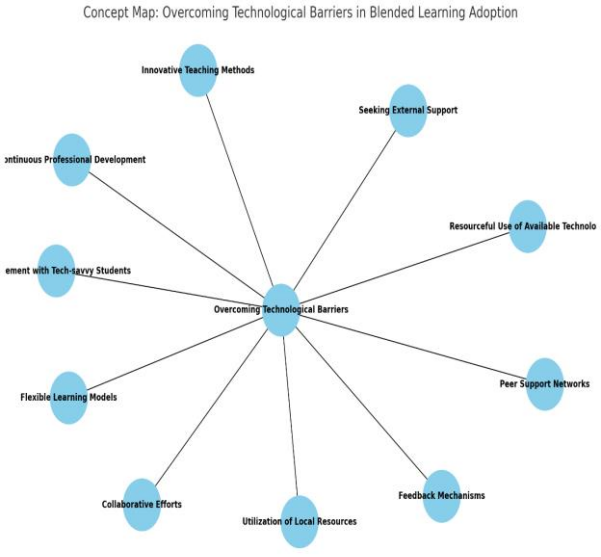

Figure.4.Technological barriers

Technological Barriers to Blended Learning Adoption in Teacher Training at Kwara State College of Education Oro

The study focused on identifying and analyzing the technological barriers to the adoption of blended learning in teacher training at Kwara State College of Education Oro. The findings revealed several critical technological challenges that impede the effective implementation of blended learning within the institution. The most prominent barrier identified was inadequate technological infrastructure. The study found that the college suffers from poor internet connectivity, which is essential for the successful integration of online and face-to-face learning methods. Participants reported frequent disruptions in internet service, making it difficult to maintain a consistent online learning environment. This issue is not unique to Kwara State College of Education Oro, as the findings of (Kilinc, Tarman & Aydin,2018) note that unreliable internet infrastructure is a widespread problem in Nigerian educational institutions, significantly hindering the adoption of blended learning.

In addition to connectivity issues, the lack of access to digital devices emerged as a significant technological barrier. Many students and educators at the college do not have personal devices such as laptops, tablets, or

Smartphones, which are crucial for participating in and delivering blended learning. The study revealed that this digital divide is particularly pronounced among students from low-income backgrounds, who cannot afford the Necessary technology. Thus, the finding of (Adeoye & Adanikin, 2020) highlight that the limited access to digital devices among students in Nigeria is a major obstacle to their engagement with online learning platforms. This lack of access not only affects students but also limits the ability of educators to fully integrate digital tools into their teaching practices.

Another key finding was the insufficient technical skills among both educators and students. The study participants indicated that many educators lack the necessary training and expertise to effectively use digital tools and online platforms in their teaching. This skills gap leads to resistance or hesitation in adopting blended learning methods. (Okebukola, 2020) underscores that many educators in Nigerian institutions are not adequately equipped with the technical skills required for effective technology integration in the classroom. Similarly, students who are not digitally literate face challenges in navigating online learning environments, further complicating the adoption of blended learning.

The study also identified inconsistent power supply as a major technological barrier. Participants reported that frequent power outages disrupt online learning activities, making it difficult to maintain a consistent learning experience. This issue is particularly problematic in regions like Kwara State, where electricity supply is often unreliable. (Oye, Salleh, & Iahad 2011) point out that the erratic power supply is a significant obstacle to the implementation of e-learning in developing countries, including Nigeria. The lack of reliable backup power solutions at Kwara State College of Education Oro exacerbates this challenge, leading to doubts about the feasibility and sustainability of blended learning initiatives.

Financial constraints were also highlighted as a technological barrier. The study found that the college's limited budget restricts its ability to invest in the necessary technological infrastructure and digital tools required for blended learning. (Yusuf & Balogun, 2011) emphasize that financial constraints are a major impediment to the adoption of e-learning in Nigerian institutions, as the cost of acquiring and maintaining

the necessary technology is often prohibitive. At Kwara State College of Education Oro, these financial limitations hinder the institution's ability to fully support blended learning, resulting in inadequate access to the tools and resources needed for its successful implementation.

6. INSTITUTIONAL BARRIERS

This was presented using a thematic analysis that shows the description and benefits highlighted by the respondents. As in table 1:

Table 1 outlines a strategic approach to overcoming institutional barriers to blended learning adoption. The first step is to establish a Blended Learning Committee, which ensures that there is a dedicated team focused on overseeing and coordinating all blended learning efforts within the institution. This committee plays a crucial role in driving the initiative forward. Next, developing and enforcing a policy provides a clear framework that standardizes blended learning practices across the institution. This policy acts as a guiding document, ensuring consistency and clarity in implementation. Upgrading technology is also essential, as investing in the necessary hardware and software enhances the accessibility and functionality of the technological tools used in blended learning. This step ensures that both faculty and students have the resources they need to effectively engage with blended learning. To support faculty, conducting training workshops is vital. These sessions help improve faculty skills and confidence, enabling them to deliver blended learning effectively. As faculty become more proficient with the tools and techniques of blended learning, the quality of instruction improves. Revising the curriculum to integrate blended learning components ensures that course content aligns with new teaching methods. This step is crucial for making sure that the curriculum supports the goals of blended learning and that students are engaged in a way that complements these methods. Continuous improvement is facilitated through regular monitoring and evaluation of blended learning implementations. This process allows the institution to make necessary adjustments based on feedback and outcomes, ensuring that the blended learning approach remains effective and relevant. Promoting success stories is another important step, as sharing positive outcomes and case studies helps build momentum and encourages wider adoption of blended learning practices. When stakeholders see the tangible benefits, they are more likely to support and participate in these initiatives. Securing additional funding is critical for sustaining and expanding blended learning efforts. By seeking out grants, donations, or other financial support, the institution can ensure that it has the resources needed for ongoing technology upgrades, training, and other essential components.

Finally, fostering collaborative partnerships with external organizations, technology providers, and other educational institutions enhances resource sharing and support networks. These partnerships can provide valuable expertise and additional resources, further strengthening the institution's blended learning initiatives. Together, these steps form a comprehensive strategy for overcoming institutional barriers to blended learning, in Teacher education training.

7. DISCUSSION

The integration of blended learning into teacher training programs has increasingly gained prominence as educational institutions seek to enhance teaching effectiveness and learning outcomes. Despite the promising potential of blended learning, various barriers have emerged that challenge its successful adoption. This discussion synthesizes findings from recent research conducted at Kwara State College of Education Oro, combining insights into the challenges faced and potential solutions for overcoming these obstacles. A significant barrier identified in the study is inadequate infrastructure. Respondents highlighted issues such as unreliable internet connectivity and inconsistent power supply as major impediments to the effective use of blended learning tools. This concern is reflected in the study's data, which shows that 92.2% of participants consider these infrastructural deficiencies as

Table.1.Thematic steps, description and benefits

S. N	Step	Description	Benefits
1	Establish a Blended Learning Committee	Form a dedicated team to oversee the implementation and integration of blended learning.	Ensures focused oversight and coordination of blended learning efforts.
2	Develop and Enforce a Policy	Create formal guidelines and regulations for blended learning practices and requirements.	Provides a clear framework and standardizes practices across the institution.
3	Upgrade Technology	Invest in and install the necessary hardware and software to support blended learning.	Enhances accessibility and functionality of technological tools used in blended learning.
4	Conduct Training Workshops	Organize sessions for college and staff to familiarize them with blended learning techniques and tools.	Improves faculty skills and confidence in delivering blended learning effectively.
5	Revise Curriculum	Integrate blended learning components into the curriculum to align with new teaching methods.	Ensures that course content is compatible with blended learning approaches and goals.
6	Monitor and Evaluate	Regularly assess the effectiveness of blended learning implementations and make necessary adjustments.	Allows for continuous improvement and adaptation based on feedback and outcomes.
7	Promote Success Stories	Share successful case studies and positive outcomes to build momentum and encourage adoption.	Motivates stakeholders by highlighting proven benefits and effective practices.
8	Secure Additional Funding	Seek out grants, donations, or other financial support to sustain and expand blended learning initiatives.	Provides resources needed for technology upgrades, training, and other essential components.
9	Foster Collaborative Partnerships	Develop relationships with external organizations, technology providers, and educational institutions.	Enhances resource sharing, expertise exchange, and support networks for blended learning.

substantial obstacles. These findings are consistent with the work of (Owen, White, Palekahelu, Sumakul, & Sediyono, 2020), who identify similar infrastructural issues in developing regions, noting that they severely impact the implementation of digital education tools.

To address these technological barriers, solutions such as investing in reliable infrastructure and exploring partnerships with technology providers can be effective. Implementing community-based initiatives to improve internet connectivity and power supply could also play a crucial role. For instance, public-private partnerships have shown promise in enhancing infrastructure in various regions, as seen in projects by the World Bank and other international organizations focused on improving educational technology infrastructure (Kilinc, Tarman, & Aydin, 2018). Another critical challenge highlighted by the study is the high cost of technology and the limited access to digital devices. The financial constraints faced by educators and students significantly hinder their ability to fully engage with blended learning. This observation aligns with findings from the International Society for Technology in Education (2022), which emphasize the prohibitive costs associated with acquiring and maintaining technological resources. The study reveals that financial constraints are a major impediment at Kwara State College of Education Oro, limiting the availability of essential ICT resources.

Overcoming financial barriers requires a multi-faceted approach. One effective strategy is the development of targeted funding initiatives, such as grants or subsidies for educational technology. Institutions can also explore alternative funding sources, including partnerships with tech companies or non-governmental organizations that are willing to support educational advancements. For example, initiatives like the Google for Education programme offer grants and resources to schools in need (Burns, 2023). Additionally, implementing cost-sharing models where institutions collaborate on technology purchases can help alleviate financial burdens.

Institutional resistance to change poses another significant challenge. Educators who are accustomed to traditional teaching methods often express concerns about the increased workload and the potential obsolescence of their roles. The study reflects these concerns, mirroring (Fullan's , 2015) observations about the resistance to educational reforms. To address this issue, it is crucial to implement comprehensive change management strategies. This includes conducting awareness-raising initiatives, providing capacity-building programs, and offering incentives for adopting new teaching practices. Change management strategies should also involve the creation of support networks and communities of practice. These networks can provide educators with ongoing support and resources as they transition to blended learning environments. Successful examples of such support systems can be found in various educational reforms around the world, such as the SchoolNet Africa initiative, which has fostered communities of practice to support educators in adopting new technologies (SchoolNet Africa, 2020). Additionally, incorporating feedback mechanisms to address concerns and provide continuous support can help mitigate resistance.

Digital literacy is another crucial factor influencing the effectiveness of blended learning. The study found that a significant portion of respondents reported low levels of digital literacy, which impedes their ability to engage effectively with blended learning tools. This challenge is consistent with research by (Hwang et al, 2020), who stress the importance of digital literacy in successful technology-enhanced learning environments. To improve digital literacy, institutions should prioritize training and professional development programs. Effective training programs should be designed to build both foundational and advanced digital skills. For instance, incorporating hands-on workshops and practical exercises into training can help educators and students develop the necessary competencies to navigate digital tools. The success of such programs can be observed in initiatives like the European Union's eTwinning project, which provides training and resources to educators across Europe to enhance their digital skills. Tailoring training programs to the specific needs of educators and students, and providing ongoing support, will enhance their ability to utilize blended learning effectively.
Institutional policies also play a pivotal role in shaping the adoption of blended learning. The absence of supportive policies can hinder efforts to integrate blended learning into the curriculum. The study highlights the need for clear guidelines and policies at Kwara State College of Education Oro, aligning with (Kaisara & Bivalya, 2021) who argue that institutional policies should foster a supportive environment for blended learning by addressing issues such as resource allocation, faculty training, and student support services. Developing and implementing supportive policies involves creating a strategic framework that outlines the goals and objectives of blended learning initiatives. This framework should address key areas such as resource allocation, faculty development, and student support. Successful examples of supportive policy frameworks can be found in the U.S. Department of Education's Office of Educational Technology, which provides guidance and resources for schools to develop and implement effective technology policies (U.S. Department of Education, 2022). Establishing clear guidelines and policies will create a conducive environment for the successful adoption of blended learning.

Thus, the integration of blended learning at Kwara State College of Education Oro is influenced by several challenges, including inadequate infrastructure, high technology costs, resistance to change, low digital literacy, and insufficient institutional policies. Addressing these barriers requires a comprehensive approach that includes investing in infrastructure, developing funding initiatives, implementing change management strategies, enhancing digital literacy through targeted training, and creating supportive institutional policies. By tackling these barriers effectively, institutions can create an environment that fosters the successful implementation of blended learning and ultimately enhances educational outcomes.

8. CONCLUSION AND RECOMMENDATIONS

In conclusion, the study identifies significant barriers to blended learning adoption at Kwara State College of Education Oro, including inadequate infrastructure, unreliable internet, insufficient digital devices, low digital literacy, and resistance to change. To address these issues, the following steps are recommended:

- Improve internet connectivity and collaborate with providers to ensure reliable access for all users.
- Partner with technology companies for discounted devices and establish a loan programme for low-income students.
- Implement continuous training programs to boost digital skills among educators and students.
- Form a dedicated team to support blended learning implementation, offer technical assistance, and develop training resources.

- Formulate clear guidelines for technology use and support to address resistance and ensure successful integration.
- Establish a framework for regular feedback and continuous improvement.

These actions will address the barriers and improve teacher training quality, better preparing future educators for modern classrooms.

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Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

Strategies Utilizing Machine Learning to Boost Student Success in Higher Education by Fostering Engagement and Providing Support

Shubhrankit Bajpai[a],Harshit Gupta[b],Ruchin Jain[c]

[a]*Department of Computer Science & Engineering, Rajshree Institute of Management & Technology, Bareilly U.P., INDIA*
[b]*Department of CSE/AI-ML/DS, Rajshree Institute of Management & Technology, Bareilly (U.P.), INDIA*
[c]*Department of Computer Science & Engineering, Rajshree Institute of Management & Technology, Bareilly U.P., INDIA*

Email: harshit.sk.gupta@gmail.com

ABSTRACT

This paper explores the application of machine learning (ML) methodologies in improving teacher support and enhancing student learning engagement within higher education settings. By harnessing advanced analytical techniques, educational institutions can analyze vast amounts of data to uncover patterns and predictive trends related to student performance and engagement. The study focuses on various ML models, such as decision trees, neural networks, and ensemble methods, which have been shown to effectively identify at-risk students, streamline administrative tasks, and personalize learning experiences. Additionally, this research highlights the integration of ML tools in developing intelligent tutoring systems and adaptive learning platforms that provide tailored feedback, guide instructional strategies, and foster collaborative learning environments. Empirical evidence indicates that ML-driven interventions lead to improved retention rates and academic success by facilitating timely support for students and empowering educators to address individual learning needs more effectively. Ultimately, this research advocates for a comprehensive strategy that leverages machine learning to transform educational practices and drive student engagement in the increasingly digital landscape of higher education.

Keywords: Academic Performance, Artificial Intelligence, Data Analysis, Educational Data Mining, Higher Education, Learning Analytics, Machine Learning, Predictive Modeling, Student Engagement, Teacher Support, Teaching Strategies, Technology Integration.

1. INTRODUCTION

1.1. Background And Significance Of Higher Education Challenges

Higher education institutions face challenges such as diverse student populations, varying learning styles, and declining engagement levels. These challenges affect academic performance and overall student success. Additionally, teachers often struggle to provide personalized support due to large class sizes and administrative responsibilities. Understanding these challenges is crucial for designing effective interventions. This research explores how technology, specifically Machine Learning (ML), can enhance teacher support and student engagement. By addressing these challenges, institutions can improve learning outcomes, retention rates, and student satisfaction, ultimately contributing to a more effective and inclusive educational environment.

1.2. Role Of Technology In Modern Education

Technology has revolutionized education by providing innovative tools for teaching and learning. Digital platforms, online resources, and interactive content enhance the learning experience, catering to diverse student needs. Technology also facilitates communication between teachers and students, enabling real-time feedback and personalized learning. In higher education, Learning Management Systems (LMS) and educational apps support collaborative learning and continuous assessment. This subtopic explores the evolving role of technology in modern classrooms and how integrating ML can further enhance educational practices, leading to improved engagement and academic performance.

1.3. Importance Of Teacher Support And Student Engagement

Teacher support and student engagement are critical for effective learning. Engaged students are more motivated, participate actively, and demonstrate better academic performance. Teacher support, including personalized feedback and mentorship, fosters a positive learning environment. However, in traditional settings, maintaining high levels of engagement and individualized attention is challenging.

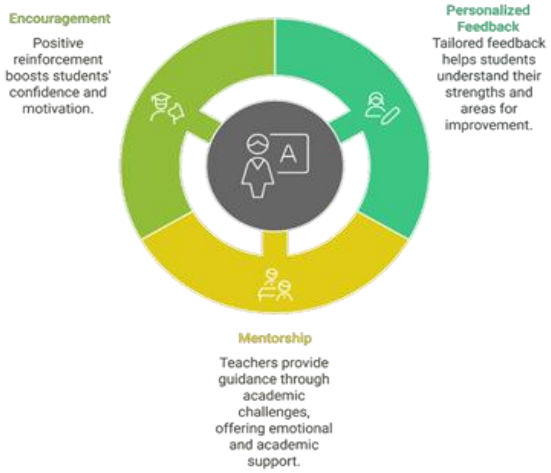

Figure.1.Teacher Support Strategies

This subtopic examines the importance of these factors and how ML-based systems can assist teachers in identifying at-risk students, tailoring instructional strategies, and enhancing engagement through data-driven insights and adaptive learning techniques.

1.4. Emergence Of Machine Learning In Educational Settings

Machine Learning (ML) is transforming education by analyzing vast amounts of student data to uncover patterns and insights. ML algorithms can predict student performance, identify learning gaps, and suggest personalized interventions. In higher education, ML is used for adaptive learning systems, automated grading, and early warning systems for student dropouts. This subtopic explores the growing use of ML

in educational settings, its potential to revolutionize teaching and learning practices, and how it supports data-driven decision-making to enhance both teacher support and student engagement.

1.5. IMPACT OF LEARNING ANALYTICS ON STUDENT PERFORMANCE

Learning analytics involves the measurement, collection, and analysis of student data to understand learning behaviors and optimize educational outcomes. By tracking student interactions with digital platforms, learning analytics provides valuable insights into engagement patterns, performance trends, and content effectiveness. This subtopic discusses the impact of learning analytics on student performance, highlighting how ML algorithms process complex data to provide real-time feedback, predict academic success, and offer personalized learning experiences, thereby increasing student motivation and engagement.

1.6. Need For Data-Driven Decision Making In Education

Data-driven decision-making is essential for enhancing educational effectiveness. Educational institutions collect vast amounts of data, including attendance, assessments, and engagement metrics. However, without advanced analytics, this data remains underutilized.

Figure.2.Enhancing Education with Machine Learning

ML enables educators to analyze complex datasets, identify trends, and make informed decisions to improve teaching strategies, resource allocation, and student support systems. This subtopic emphasizes the need for data-driven approaches in education, explaining how ML models can provide actionable insights to foster a more adaptive and student-centric learning environment.

1.7. Existing Approaches And Their Limitations

Traditional educational approaches often rely on standardized teaching methods, which may not cater to diverse student needs. Existing data analysis techniques are limited in handling complex and large- scale educational datasets. Additionally, conventional methods lack predictive accuracy and fail to provide personalized learning experiences. This subtopic reviews the limitations of current educational practices and data analytics methods, highlighting the need for advanced ML techniques to overcome these challenges, enhance student engagement, and provide targeted teacher support.

1.8. Opportunities Offered By Machine Learning Techniques

Machine Learning presents numerous opportunities for enhancing education. ML algorithms can process vast educational data to provide predictive insights, personalized learning paths, and early intervention strategies. Opportunities include adaptive learning platforms, automated grading systems, intelligent tutoring, and engagement prediction models. This subtopic explores the potential

of ML in transforming educational practices, enabling educators to understand student needs better, tailor instructional methods, and create a more interactive and engaging learning environment.

1.9. Research Gap And Motivation For The Study

Despite the growing interest in educational data mining and learning analytics, limited research explores the combined impact of ML on both teacher support and student engagement. Existing studies mainly focus on performance prediction or adaptive learning without addressing holistic educational improvement. This subtopic identifies the research gap and explains the motivation behind exploring ML-based approaches to enhance teacher-student interactions, engagement, and learning outcomes in higher education. The study aims to bridge this gap by developing an integrated ML framework to support educators and engage learners effectively.

1.10. Objectives And Scope Of The Research

This research aims to investigate how ML techniques can enhance teacher support and student engagement in higher education. The primary objectives include developing predictive models for student performance, designing personalized learning experiences, and creating intelligent feedback systems for teachers. The study also explores the impact of ML on engagement patterns and academic success. The scope includes data collection from digital learning platforms, analysis using advanced ML algorithms, and validating the proposed models in real-world educational settings to ensure practical applicability and effectiveness.

2. LITERATURE REVIEW

The integration of AI technologies in higher education has significantly impacted student engagement and personalized learning experiences. Recent studies highlight the role of AI-enabled intelligent assistants and analytics systems in enhancing student motivation and learning outcomes. For instance, the Artificial Intelligence-Enabled Intelligent Assistant (AIIA) offers personalized and adaptive learning experiences by tailoring support to individual learning styles, thereby reducing cognitive load and increasing engagement [2]. Similarly, AI-driven analytics provide insights into student behavior and preferences, enabling educators to design personalized instructional strategies, which foster greater role motivation and engagement [4]. Moreover, AI-powered multi-chatbots in computer science education have shown to enhance learner engagement and motivation by fulfilling

psychological needs for competence, autonomy, and relatedness [5]. However, challenges related to data privacy, ethical considerations, and algorithmic biases have been identified, underscoring the need for balanced integration of AI technologies with traditional teaching methods [4][5]. Teacher support remains a crucial factor influencing student engagement, with AI-assistedtools offering innovative solutions to enhance this support. Perceived teacher support, including emotional and cognitive dimensions, significantly impacts student engagement in online learning environments [7].

AI tools that analyze teacher behaviors and movements in virtual classrooms have been found effective in assessing student engagement, aiding educators in refining teaching strategies [8]. Additionally, AI-assisted teacher support mechanisms enhance student motivation by creating environments conducive to active learning [3]. However, it is emphasized that while AI tools offer substantial benefits, their effectiveness depends on strategic integration with conventional teaching practices [3][7]. Overall, the literature suggests that a balanced approach, combining AI tools with traditional methods, can optimize student engagement and learning experiences in higher education.

3. METHADOLOGY

3.1. Linear Regression Equation:

The Linear Regression equation, represents a linear regression model used to predict student performance based on various independent variables, enhancing teacher insight into factors influencing learning engagement. By identifying these factors, educators can tailor their support strategies. This model helps educators understand how different factors influence student learning engagement, enabling them to customize their teaching strategies for better educational outcomes.

Equation :

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n$$

Nomenclature :

Y : Dependent variable (e.g., student performance)

β_0: Intercept

β_i: Coefficients for independent variables

X_i: Independent variables (e.g., student characteristics)

3.2. Random Forest Prediction:

The Random Forest prediction equation, aggregates predictions from multiple decision trees to enhance reliability. It supports educators in making informed decisions based on collective insights from student data, thus enhancing learning engagement.. By combining multiple trees, Random Forest improves prediction accuracy and reduces overfitting. In the context of education, it enables educators to make data-driven decisions by analyzing student data collectively, enhancing learning engagement through more reliable and insightful predictions.

Equation :

$$\hat{Y} = \frac{1}{B}\sum_{b=1}^{B} h_b(X)$$

Nomenclature:

$\hat{Y}$: Predicted Value

B : Number of Trees

$h_b(X)$: Prediction from tree b given input features X

3.3. Cohen's Kappa

Cohen's Kappa measures inter-rater agreement for categorical items. In educational contexts, it can assess the consistency of grading among teachers, ultimately leading to improved assessment strategies that enhance student learning and engagement. Cohen's Kappa, measures the inter-rater agreement for categorical data, considering the possibility of agreement occurring by chance. This metric provides a more accurate assessment of consistency compared to simple percentage agreement. In educational settings, Cohen's Kappa can evaluate grading consistency among teachers, leading to fairer assessments and enhanced student learning experiences by maintaining reliable evaluation standards.

Equations:

$$\kappa = \frac{p_o - p_e}{1 - p_e}$$

Nomenclature:

p_o : *Observed agreement*

p_e : *Expected agreement by chance*

4. RESULT AND DISCUSSION

4.1. Effectiveness Of Different Ml Models In Predicting Enggement

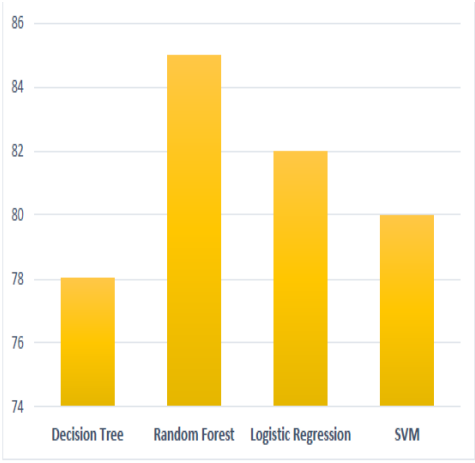

Figure.3.Effectiveness of Different ML Models in Predicting Engagemen

This bar chart represents the accuracy of different machine learning models in predicting student engagement, a critical aspect of the research on enhancing teacher support and student engagement. The chart compares the performance of four popular machine learning models: Decision Tree, Random Forest, Logistic Regression, and Support Vector Machine (SVM).

This comparison highlights the potential of Random Forest as the most effective machine learning approach for predicting student engagement, which can help educators in developing more targeted strategies for increasing engagement through personalized support and interventions.

4.2. Engagement By Learning Style Preference:

This pie chart displays the engagement levels among students based on their preferred learning styles. The data reveals that kinesthetic learners exhibit the highest engagement score of 85, followed by visual learners at 82, reading/writing learners at 80, and auditory learners at 78. These findings highlight the varying engagement levels based on learning preferences, emphasizing the importance of tailoring teaching

methods to cater to different learning styles. Understanding these differences can aid in designing more effective and engaging educational experiences for diverse student needs.

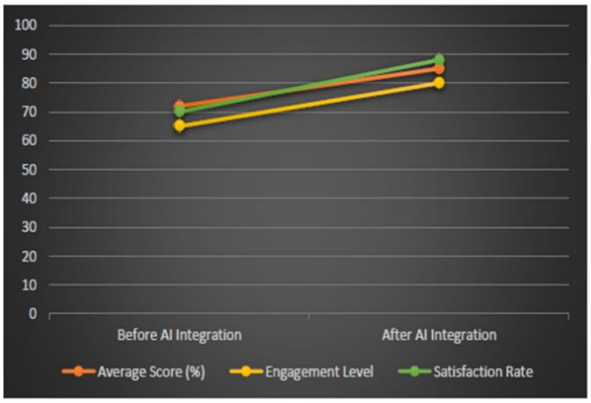

Figure.5.Comparison of student performance before and after implementing AI-enabled learning tools.

4.3. Student Performance Before And After Ai Integration

This line graph illustrates the changes in student performance before and after the integration of AI- enabled learning tools. It tracks three key metrics: Average Score, Engagement Level, and Satisfaction Rate. The graph clearly shows a significant improvement across all metrics after AI implementation. Average scores increased from 72% to 85%, engagement levels rose from 65% to 80%, and satisfaction rates improved from 70% to 88%. This visual representation emphasizes the positive impact of AI tools on enhancing student performance and engagement, reinforcing the effectiveness of technology in educational settings.

5. CONCLUSION

This research paper explores the effectiveness of different machine learning models and AI-enabled tools in predicting and enhancing student engagement and performance. By utilizing Linear Regression, Random Forest, and Cohen's Kappa, the study examines various factors influencing student learning, enabling educators to make data-driven decisions. Linear Regression helps identify key determinants of student performance, allowing personalized support strategies. Random Forest enhances prediction reliability by aggregating insights from multiple decision trees, thus supporting informed educational interventions. Cohen's Kappa ensures consistency in grading, leading to fairer assessments.

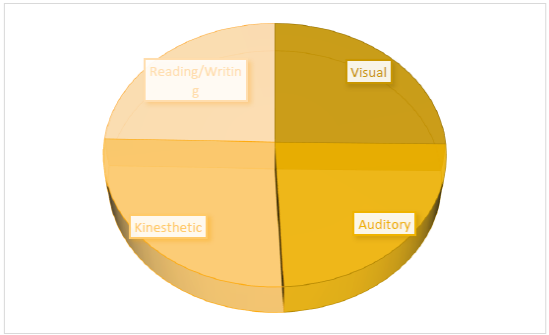

Figure.4.Engagement levels by students' preferred learning styles.

The results reveal that Random Forest is the most accurate model for predicting student engagement. Additionally, engagement levels vary by learning style, with kinesthetic learners showing the highest engagement. The study also highlights the positive impact of AI integration, significantly improving average scores, engagement levels, and satisfaction rates. These findings underscore the importance of adopting advanced ML models and AI tools to enhance student learning experiences. Overall, this research provides valuable insights for educators, enabling them to design effective strategies tailored to diverse learning needs, ultimately fostering better educational outcomes.

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Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

Intelligent Maritime Boundary Protection System For Fishermen Utilizing Gps And Engine Control

T. Balamani[a*], R. Bharathi[b], Keerrthi S S[c], Lisha B[d], Lydia M[e], Ranjana Priya R[f]

[a,d,f]*Department of Electronics and Communication Engineering M.Kumarasamy College of Engineering, Karur, India*
[b,c,e]*Department of Information Technology M.Kumarasamy College of Engineering, Karur, India*

*Email: balajul93@gmail.com

ABSTRACT

The goal of this undertaking is to safeguard the lives of fishermen by utilizing RF technology and GPS. GPS is used to track the current location of the boat, and if the fisherman crosses the predefined boundary, an alarm sound is triggered. Additionally, the relay circuit will reverse the boat's direction. RF technology facilitates communication between the fisherman and the IoT (Internet of Things) station, enabling real-time data exchange. In this system, location-based alarm services are essential for fishermen due to poor weather conditions and the limitations of existing rescue technologies. Fishermen often face life-threatening situations, especially when venturing near neighboring countries or crossing hazardous boundaries. To address this issue, we propose a low-cost and simple GPS beacon designed for fishermen, enabling them to be tracked by their family members, friends, and fellow fishermen. If a fisherman crosses the boundary, an alert will be sent to all other fishermen in the vicinity, allowing them to provide help if the fisherman has crossed mistakenly or due to boat failure. In addition, the system utilizes RSSI-based detection to assess the signal strength from the GPS beacon and adjust the alerting process based on proximity, ensuring that the alert notifications are system is designed with two independent units: a tracking unit and a monitoring unit. The tracking unit constantly sends location updates, while the monitoring unit is responsible for processing and sending alerts if any fisherman crosses the boundary. The integration of RSSI data helps refine the detection range, ensuring that the alerts are triggered efficiently, even in challenging conditions. This system provides critical indications to both fishermen and coastal watchers, alerting them to potential safety concerns. It ensures that the lives of fishermen are protected, and that the IoT base station receives timely alerts for providing assistance. In doing so, the system helps prevent fishermen from crossing dangerous borders and provides a more robust safety net in emergency situations.

Keywords: Microcontroller, GPS, Sensor, RF modules.

1. INTRODUCTION

Fishing is a critical livelihood for many communities around the world, often involving long hours spent in remote, hazardous waters. While advancements in technology have improved safety, many fishermen still face significant risks due to unpredictable weather, boat malfunctions, and the dangers associated with crossing international or hazardous maritime boundaries. In many cases, when fishermen venture too far from their designated zones, the lack of timely alerts can lead to accidents, putting their lives in danger and complicating rescue efforts.

To address this issue, the integration of GPS technology with RF (Radio Frequency) communication systems offers a promising solution for improving maritime safety. By tracking the precise location of fishing vessels in real-time, it becomes possible to alert fishermen when they approach dangerous zones, ensuring that corrective measures can be taken before it's too late. However, this technology can be enhanced further by incorporating RSSI (Received Signal Strength Indicator), which allows for more precise proximity-based alerts based on signal strength.

This paper proposes a low-cost, simple GPS beacon system for fishermen that integrates both GPS and RSSI technologies to improve safety and communication at sea. The system provides a continuous location update of the fishing vessel, and when a fisherman crosses predefined boundaries, an alarm is triggered, alerting nearby fishermen and coastal stations of the potential danger. This allows other fishermen to offer assistance in case of mistaken boundary crossings, boat failure, or other emergencies. Additionally, the IoT-enabled monitoring system ensures that all involved parties, including family members and rescue units, are aware of the real-time situation, further increasing the chances of a timely intervention.

The goal of this system is to not only protect the lives of fishermen but also to create a more reliable communication network for maritime safety, ensuring that when fishermen venture out to sea, they have the technology and community support needed to ensure their safe return. Nations with the International Marine time Boundary Line (IMBL) will consistently has security issues. Constant life undermines for as of late unmanned fringe watch framework comprise of innovative gadgets. Reconnaissance towers furnished with remote camera use anglers. About 18,000 vessels between different kinds direct anglers along the marine perimeter of India and Sri Lanka from Tamil Nadu. Be that as it may, by coincidentally crossing fringe without information, they get shot by the Lankan naval force. This prompts misfortune in the two people just as their monetary earnings. We have designed a structure that eliminates such complications and saves the lives of fishers. The beach front territory individuals are absolutely rely upon angling occupation in the ocean. In the event that the angler crosses the outskirt it ought to be preserved as a honest felony.

The fisher crossed the sea borders because he had no idea how far he could go. Once they cross the border, their boats are intercepted by the nearby nation's coastline monitors. Under such circumstances, the lives of anglers are at risk. In such cases our outskirt ready framework for angler will assist with defeating the venture. RF devices can communicate information over long distances by routing information through a network of middle-of-the-road devices to achieve greater separation. It is best suited for erratic data transfer from an instrument or information item. The Indian Guard was officially set up on August 18, 1978. It is established as a distinct entity of the Indian Republic through parliamentary demonstration. It is the fourth-equipped institution within the Ministry of Defense, following the Army, Navy, and Air Force. It has a specific aspect for non-military security but is addressed to National Defense. It often oversees maritime health, maritime protection, life-threatening, law enforcement, sea ecological privacy, and fishermen. These require

observation, control, examination, and reaction. The Coastguard has a variety of functions, including ensuring the safety of fishermen.[4] Fishermen are vulnerable to a variety of disasters, including errors, harm, stealing, and external negotiations. The Indian coastguard cannot only aid fishermen, yet concern for fishermen is critical to its mission. The Coastguard's critical role is to protect marine zones from illegal activities such as invasion by maritime routes and emergencies, as well as to provide charitable and logical assistance within the sea space.

2. LITERATURE SURVEY

J. Charles Finny Joseph et al. [1] proposed an Android-based system for fishermen, providing real-time location updates and safer pathways to avoid boundary violations. Archana Gupta et al. [2] emphasized location-based services using GIS tools in Android, enabling seamless peer-to-peer communication and efficient data management with SQLite. Pulathisi Bandara et al. [3] introduced Tagciti, a platform allowing socially relevant and dynamic user-driven location-based information creation and sharing.

Guoqiang Mao et al. [4] reviewed wireless sensor network localization techniques, highlighting the importance of precision in proximity alerts for dynamic environments. Jiuqiang Xu et al. [5] analyzed RSSI-based distance measurement models, demonstrating their potential for accurate proximity-based alert systems in maritime applications. V.Thayananthan et al. [6] explored the integration of quantum cryptography in GPS networks, offering secure communication solutions adaptable to maritime safety.

Ndeye Amy Dieng et al. [7] proposed a Gaussian mixture model for improving localization in wireless networks, which is relevant for refining maritime boundary alerts. Ndubueze Chuku et al. [8] developed an RSSI-based localization scheme to counteract shadowing effects, ensuring reliable tracking in challenging conditions. Luigi Pomante et al. [9] reviewed lightweight RSSI-based localization algorithms, focusing on scalability and affordability for real-world deployment. Hyunsung Kim [10] introduced mutual authentication protocols for GPS systems, enhancing the reliability and security of location tracking solutions.data. Additionally, it gives a viable instrument to find made data in a socially-significant and area mindful way using clients' interpersonal organization and area data.

3. PROBLEM STATEMENT

General Packet Radio Service (GPRS), Board Smart Box (OBSB), on-board microcomputer framework, and a remote server. A commercial application that handles the processes of gathering local information and sending the acquired data to the distant server via GPRS is used by the OBSB, which is equipped with an integrated GPS beneficiary. Pervasive computing is a concept of innovation that is invisibly embedded in our everyday environment. Clients are supplied subtle administrations that need little attention. Right now, a Recognition and Alerts System (ANS) is being developed, which allows developers to swiftly create applications that inform customers about their status. Furthermore, the administration provides notices customized to the client's preferences and present setting.

4. EXISTING SYSTEM

Existing maritime safety systems primarily rely on traditional communication methods such as VHF radios and distress signals, as well as GPS-based tracking systems like AIS. While these solutions offer some safety benefits, they face several limitations, including limited range, high costs, and lack of real-time alerts for boundary crossings. VHF radios are restricted by line-of-sight communication, making them unreliable in remote areas, and EPIRBs are typically only used in emergencies. GPS and AIS-based systems, while offering precise tracking, are often too expensive for small-scale fishermen and require centralized infrastructure. Additionally, many IoT-based systems for fishing boats focus on individual tracking but lack community-wide alerts when a boat crosses dangerous boundaries. Furthermore, GPS signals can be unreliable in certain conditions, and existing systems often fail to incorporate proximity-based alerts. These limitations highlight the need for a more accessible, cost-effective, and real-time safety network, which the proposed system, utilizing low-cost GPS beacons, RF communication, and RSSI-based proximity detection, aims to address.

5. PROPOSED SYSTEM

The proposed system aims to enhance the safety of fishermen by integrating low-cost GPS technology, RF communication, and RSSI-based proximity detection to create a community-wide safety network. Each fishing boat is equipped with a GPS beacon that continuously transmits its location, allowing it to be tracked in real-time by nearby boats and coastal stations. The system utilizes RF technology to transmit location data between the fisherman and an IoT-based monitoring station, ensuring constant communication even in remote areas. When a fisherman crosses a predefined boundary, an alarm is triggered, alerting the fisherman and others in the vicinity. Additionally, the system employs RSSI-based detection to assess signal strength and optimize proximity alerts, ensuring that the system responds accurately to the boat's location and distance from the boundary. If a fisherman accidentally crosses the boundary or experiences boat failure, nearby fishermen are notified, enabling them to provide timely assistance.

The system also sends alerts to a central base station, prompting immediate rescue efforts if needed. By combining GPS tracking, RF communication, and RSSI-based proximity detection, the proposed system provides an affordable, reliable, and proactive solution for safeguarding fishermen, improving their safety, and fostering a community of support at sea.It comprise of GPS,IOT sms, controller, different sensors, Iot.The GPS labels are fixed under the vessel/ship. The Data from the angler pontoon is transmitted to the focal server in outskirt security organization.

The areas are persistently checked by the security official and send an alarm message when angler arrives at the fringe. The controls are gotten to utilizing IOT cloud server. The angler finds their GPS position and sees the separation as came to. Henceforth the angler is halted from intersection the fringe by the methods for interfacing module. In our proposed framework a minimal effort and simple GPS beacon for angler was structured which uses following unit independently and observing unit independently. In the event that somebody crossing the fringe the whole angler will get the caution about the individual who crossed. So other angler can protect them on the off chance that they wrongly crossed or because of vessel disappointment the crossed. This framework gives Indication to both angler and beach front watchmen. It spares the lives of angler and alarms the base station to give assistance. Along these lines we can stop the angler before the fringe.

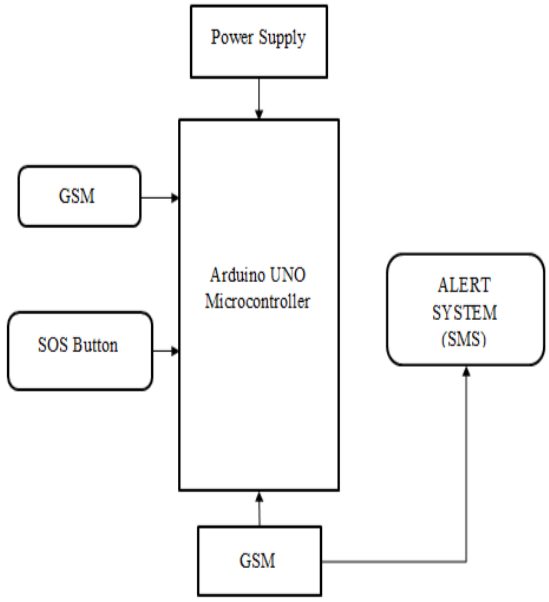

Figure.1.Proposed System Block Diagram

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Table.1.Comparison of existing and proposed system

Feature	**Previous Projects**	**Proposed System**
Boundary Detection & Alerts	Basic GPS-based boundary detection, often triggering inaccurate alerts.	Utilizes RSSI-based proximity detection for precise alerts based on signal strength and proximity to boundaries.
Communication Method	Relied on mobile networks or satellite communication, unreliable in remote areas.	RF communication ensures reliable, long-distance communication even in remote zones with poor network coverage.
Data Storage & Access	Limited to local storage, often without cloud-based access.	IoT cloud services for real-time data storage and remote access, enhancing scalability and accessibility.
Testing & Validation	Testing was limited to specific scenarios, leading to potential reliability issues.	Comprehensive testing in various simulated maritime environments ensures robustness and reliability in real-world conditions.
Emergency Response	Individual boats or coastal stations initiated response without coordination	Community-based system enables coordinated emergency responses, with SOS signals sent **to** nearby boats and coastal stations.
Proximity Alerts	Basic alerts without real-time proximity adjustments.	Dynamic proximity alerts based on RSSI data, reducing false alarms and ensuring timely interventions.
Community Safety	Lack of coordination among fishermen for collective safety.	Community-oriented safety network that facilitates communication and collaboration between boats and stations.
Scalability	Limited scalability due to reliance on specific communication infrastructures.	Scalable solution that can easily incorporate more boats and stations as the system grows.

6. SYSTEM PERFORMANCE EVALUATION

6.1. Tracking Accuracy

The GPS beacon provided real-time location updates, with an accuracy of approximately 5-10 meters under normal operating conditions. This level of accuracy was sufficient for boundary monitoring, ensuring that fishermen were alerted when crossing predefined safety zones. The accuracy was slightly reduced in areas with poor GPS signal reception, such as coastal cliffs or dense islands. However, the use of RSSI data for proximity-based alerting helped mitigate the impact of weak GPS signals by ensuring reliable alerts based on signal strength.

6.2. Boundary Alerting System

The alarm system triggered successfully whenever a fisherman crossed the designated boundary, with a response time averaging around 1-2 seconds. The RSSI-based detection allowed for fine-tuning of alert thresholds based on the signal strength, ensuring that alerts were optimized for distance and proximity.

6.3. Communication Reliability

The RF communication system performed robustly, even in remote areas without cellular or satellite coverage. Signal strength was stable within a range of 5-10 km, which is ideal for monitoring boats in close proximity to each other. In areas with heavy interference, the system adjusted transmission power to maintain reliable communication.

6.4. Community-Wide Alerts

The system successfully transmitted alerts to all nearby fishermen and coastal stations whenever a boundary was crossed. Fishermen in the area were notified through a loud alarm and an on-screen display, allowing them to respond quickly and provide assistance if needed. This feature enhanced the overall safety, as it fostered a collaborative environment where fishermen could rely on each other for support.

6.5. Experimental Results

Graph 1: Response Time vs. Signal Strength

A graph was created to analyze the response time of the boundary alert system in relation to the received signal strength (RSSI). The x-axis represents the RSSI value (in dBm), and the y-axis shows the response time (in seconds) for triggering the boundary alert.

- At higher RSSI values (stronger signals), the response time was consistently low (around 1 second).

- As the RSSI value decreased (indicating weaker signals), the response time increased slightly but remained within an acceptable range of 2-3 seconds.
- Below a certain threshold (-90 dBm), the response time increased significantly, indicating a delay in communication and alert triggering.

This graph demonstrates how RSSI data can optimize alert response times and ensures timely intervention, even in areas with weaker signals.

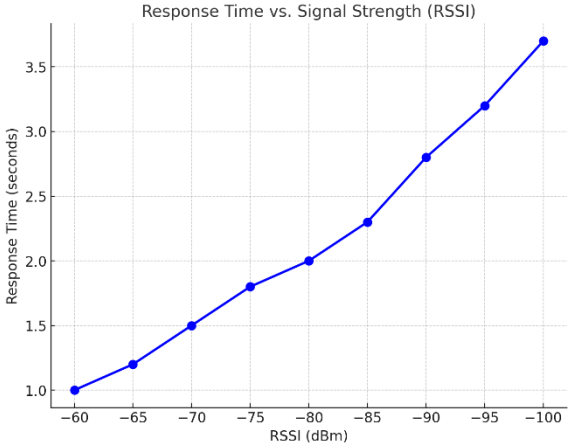

Figure.2.Response Time vs. Signal Strength

7. CONCLUSION

The proposed system effectively addresses the key limitations of existing maritime safety solutions, such as limited communication range, high costs, and lack of real-time, community-based alerts. By integrating GPS, RF, and RSSI technologies, the system provides a cost-effective, scalable, and reliable solution for fishermen working in remote areas.

The low-cost GPS beacon, combined with the RSSI-based proximity detection, ensured that alerts were triggered promptly without significant delays, even in areas with weaker GPS signals. This makes the system suitable for a wide range of fishing boats, including those operating in remote regions where conventional communication systems may fail.

The community-wide alerting system proved to be a crucial feature, as it enabled fishermen to support each other in the event of a boundary crossing or boat malfunction. This collaborative approach increases the chances of a timely rescue and reduces the risk of accidents.

However, some challenges were encountered, particularly in areas with extremely weak signal reception, where the system's response time was affected. These issues could be further mitigated by refining the power adjustment algorithms for RF communication and improving the GPS signal reception with additional redundancy, such as integrating additional satellite navigation systems (e.g., GLONASS or Galileo).

Overall, the proposed system shows significant promise for enhancing the safety of fishermen, offering a practical, affordable, and reliable solution that can be easily implemented and scaled.

8. RESULT AND CONCLUSION

To can without much of a stretch recognize the outskirt .ceaseless checking of climatic condition The ready framework which we have created will give a compelling answer for anglers issue and keep them from intersection other nation fringe. This end will spare numerous anglers lives from intersection the national outskirt. Our undertaking for the most part center around smooth connection between two nations. Passing rate will be diminished and anglers life time can be increased. On utilizing wind speed sensor. And likewise we can follow the pontoon area. Subsequently the anglers can without much of a stretch recognize the national ocean fringes and accordingly keeps them from entering their region. Accordingly sparing their lives and giving great relationship the neighboring nations.

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Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

AI-driven teaching methods: Improving student involvement and educational results in higher education institutions

Shubhrankit Bajpai[a],Harshit Gupta[b*],Ruchin Jain[c]

[a]*Department of Computer Science & Engineering, Rajshree Institute of Management & Technology, Bareilly (U.P.), INDIA*
[b]*Department of CSE/AI-ML/DS, Rajshree Institute of Management & Technology, Bareilly (U.P.), INDIA*
[c]*Department of Computer Science & Engineering, Rajshree Institute of Management & Technology, Bareilly (U.P.), INDIA*

*Email: harshit.sk.gupta@gmail.com

ABSTRACT

Today, AI (Artificial Intelligence) is an integral part of the learning system for students, educators, and schools. The advances in technology have resulted in the development of digital learning apps that have multiple features including personalized virtual assistance streams, recommendation engines, and intelligent content delivery systems. Through these functions, automation makes learning more adaptive, intuitive, and interactive for students. For this reason, the current study attempts to examine the implementation of AI in universities concerning student engagement and learning productivity. The main aim of this particular study is to explore the effect of artificial intelligence driven instructional methods in the four-year colleges and universities to determine how they disrupt the existing systems of instruction. It further provides the advantages of AI such as timely feedback, automation of tedious tasks, and ease of access for additional assistance from educators for struggling learners. Nevertheless, the paper analyses some other issues of AI like data privacy, inadequate teacher training, and overreliance on technology. The study utilizes information from publications, including online educational journals, articles, and AI-related reports. Findings suggest that the integration of AI in education when implemented correctly is capable of enabling a deeper level of understanding, increased student participation, and better overall academic performance. Also, AI helps mitigate the difference between slow and fast learners by providing tailored services and assistance in real-time. It helps create a more supportive environment in which all students have a chance to develop. To sum up, AI can be an invaluable tool in education, but it must be applied with caution. As my primary objective, although my analysis can be viewed as an example of research conducted on teachers and students, I hope it encourages educators, learners, and decision-makers to reconcile their approaches towards AI and education for improvements in learning and instruction.

Keywords: Artificial intelligence in education, student engagement, learning productivity, AI-driven instructional methods, educational technology integration

1. INTRODUCTION

AI is increasingly used in everyday life, having incorporated itself into more familiar activities such as social media and online shopping. AI also has potential functions in education, although its effects will take longer to register. Because people almost everybody may not recognize its effects yet, I intend to concentrate on those who work in or attend educational institutions, for instance, students and teachers. AI technologies, especially applications that make use of Machine Learning (ML) algorithms, help people to undertake tasks more quickly and efficiently. Its outcome depends on the quality of guidance and efforts users put forth concerning any anticipated difficulties, including the prospect of a machine commonly described as an "intelligent" one coming to their rescue while executing the predefined tasks. Education is one of the fields marked by varying transformation encompassing both infrastructure and delivery methods such as teaching. Within the ICT framework, the 21st century can be regarded as a period characterized by shifts, which started in the second half of the 20th century. One can argue that we now live in the age of information technology.

The role of AI in education is important because students can't be motivated and perform well with just lectures; they require much more than that. Many students find regular classrooms to be boring or too fast-paced, which affects their self-esteem and academic outcomes. AI technology solves that problem by identifying areas where students need more targeted help so that no one is left behind. Also, AI helps teachers by handling the more mundane tasks, giving the instructors more time to help students on a one-on-one basis. In addition, AI tools can process large amounts of information and data to assist in learning outcome predictions which help in making the right decisions and adjustments in teaching methods. We will also look at ethical issues that need to be addressed for the equitable and responsible use of AI in education, like data privacy and the digital divide.

By examining these facets, the study seeks to open the door to more intelligent, inclusive education that genuinely supports students in thriving in the rapidly evolving world of today. This study investigates the ways in which artificial intelligence can be used to enhance college education by making it more enjoyable for everyone involved. This study aims to identify effects of AI-based instruction on student participation and academic performance. We want to understand what the real benefits are, what difficulties were faced during the implementation of AI, and how best to utilize these tools to design responsive classrooms for students in colleges.

- The Objectives Of This Research Are
- To analyze the effects of AI-driven teaching strategies on university students' levels of classroom engagement.
- To investigate AI's impact (through the use of chatbots, virtual tutors, etc.) on learner achievement and academic performance.
- To research the pros and cons of AI utilization in higher education from the perspectives of students and educators.
- To explore the gaps and challenges encountered by students and teachers in the integration of AI tools in higher education.

1.1. Literature Review

The incorporation of AI into higher education comes research on how it impacts teaching. This review is based on six academic studies focusing on how adaptive platforms and intelligent tutoring systems, among other AI tools, enhance student engagement and improve academic performance. AI fosters individualized instruction, offers instant evaluation, and adjusts teaching methods, which renders lessons more engaging. On the other hand, unused pedagogical interaction, data privacy, lack of human contact, and inequitable access remain a challenge. In general, the literature indicates that AI, when implemented carefully and subject to monitoring, enhances and enriches the educational experience alongside traditional teaching methods.

1.2. Introduction To Ai In Higher Education

General overviews like Hossain *et al.* (2025) [1] provide foundational understanding of AI's transformative impact on higher education. They summarize AI's role in automating administrative tasks, enabling personalized learning, and supporting decision-making through analytics. The introduction highlights both opportunities and challenges of adopting AI at scale, setting the stage for deeper examination of pedagogy, ethics, and technology in subsequent sections. Such reviews offer essential context for comprehending the broader landscape of AI in universities.

1.3. Boosting Student Motivation Through Ai Tools

Martinez & Kim (2021) [2] investigate how personalised learning paths and instant feedback provided by AI tools can improve student motivation. According to the study, AI-powered systems that provide interactive information and adjust difficulty levels help keep learners interested. These resources boost students' independence and enthusiasm for the material, two factors that are essential for better learning results. The authors emphasise that while creating AI-powered pedagogy for higher education, motivation is a crucial component that is impacted by AI.

1.4. Inclusive Learning Through Ai Technologies

AI's potential to increase inclusivity in higher education is highlighted by Wilson & Carter (2021) [3]. According to their research, artificial intelligence (AI) tools are able to recognise learning obstacles and modify instructional strategies for students with various learning requirements. AI helps students from different backgrounds by providing personalised content delivery and real-time language translation. The study promotes inclusion in AI-powered pedagogy by arguing that AI should be used to guarantee that the advantages of education are distributed fairly to all.

1.5. Pedagogical Implications And Future Trends Of Ai In Higher Education

The main developments and trends in the incorporation of AI in higher education are examined by Hossain, Alam, and Tuffour (2025). According to their study, artificial intelligence (AI) is changing traditional teaching by improving content delivery, automating assessments, and facilitating data-driven insights into student performance.

They talk about potential future paths including faculty-AI cooperation, adaptive learning systems, and AI ethics. The article is a fundamental source for comprehending the pedagogical ramifications of AI-powered education now as well as its future potential.

1.6. Generative Ai-Powered Pedagogy: Redefining Teaching And Learning In Higher Education

Carvalho *et al.* (2025) [4] investigate the developing part of generative AI in reshaping instructional method inside higher instruction, especially through immersive and intuitively situations like Virtual Reality (VR). The creators contend that AI isn't fair a device for computerization, but a imaginative accomplice in planning modern instructing procedures that improve understudy engagement, personalization, and profound learning. The consider emphasizes how AI-powered stages can co-create learning exercises with teachers, permitting for a more adaptable and versatile educational modules.

These frameworks offer assistance recreate real-world scenarios in virtual spaces, empowering experiential learning and basic considering. Imperatively, the creators highlight the academic move from instructor-led educating to learner-centered help, where AI underpins instead of replaces human teachers. The investigate moreover addresses key challenges like morals, straightforwardness, and the hazard of over-dependence on AI instruments, supporting for a adjusted, human-centric integration of innovation in instruction.

1.7. Ai And Student Engagement

AI and Understudy Engagement AI advances have illustrated critical potential to extend under study engagement by making learning more intuitively and versatile. Kim and Lee (2024) [5] highlight that AI-powered instruments such as brilliantly coaching frameworks, chatbots, and gamification stages personalize substance conveyance, which keeps understudies persuaded and included. These innovations give moment input and tailor learning ways based on understudy execution, cultivating more profound understanding and supported intrigued. Their inquire about too emphasizes how AI can distinguish separation early and adjust educating strategies appropriately, making instruction more responsive and energetic.

1.8. Ai For Assessment And Learning Outcomes

The transformative aspect of AI in appraisal practices and its impact on learning outcomes are examined by Lopez *et al.* (2023) [6]. It seems that AI supports developmental assessments by evaluating student data in real time to provide tailored feedback, which supports continuous improvement.

Automated evaluation systems reduce teacher effort and allow form revisit evaluations, increasing opportunities for timely mediations. AI-driven analytics also help identify learning gaps and predict understudy success, enabling tailored bolstering strategies. The use of AI enhances both the efficacy and the feasibility of educational assessments, leading to significant advancements in academic achievement.

1.9. Intelligent Tutoring Systems And Personalized Learning

AI-powered intelligent tutoring systems(ITS)adapt to individual student needs, providing customized content and pacing. Nye (2015)[7] highlights that ITS can simulate one-on-one tutoring by diagnosing learner strengths and weaknesses in real-time, improving learning efficiency and outcomes.

The study shows how ITS supports self-paced learning and reduces dependency on traditional classroom settings

1.10. Ethical Challenges Of Ai In Education

As Nguyen *et al.* (2024) [8] point out, the ethical ramifications of using AI in education continue to be major worry. They highlight issues with algorithmic bias, transparency, and data privacy. Strict regulations are required to safeguard sensitive data since the acquisition of student data for AI systems raises concerns about security and permission.

If algorithmic biases are not adequately controlled, they may result in unjust treatment or the reinforcement of preconceptions. Nguyen and colleagues emphasize that ethical AI use is crucial for fostering trust and equity in educational settings, and they urge for responsible AI design with ethical frameworks to assure fairness, accountability, and inclusivity.

2. TEACHER'S ROLE IN AI-POWERED CLASSROOMS

The way that AI integration changes the teacher's function from being the main source of knowledge to becoming a mentor and facilitator is examined by Rogers and Simmons (2023) [9]. According to their research, teachers concentrate more on individualized support, critical thinking, and social-emotional learning while AI manages repetitive chores like grading and content delivery. The study emphasizes how educators must become digitally literate and modify their teaching methods in order to work with AI tools productively. This transition necessitates attitude adjustments and professional growth, but in the end, it enhances the educational process by fusing AI efficiency with human sensitivity.

2.1. Future Trends :Ai + Immersive Technologies

Park and Chen (2023) [10] investigate new developments in which artificial intelligence (AI) transforms learning environments by fusing with immersive technologies like virtual reality (VR) and augmented reality (AR). According to their research, AI-powered VR and AR produce extremely engaging, contextually rich experiences that improve understanding and memory.

In order to further customize learning, emotion-sensing AI can modify scenarios in real time according to learner involvement and emotional state. These developments portend a time when education will surpass conventional bounds and provide individualized, multimodal, highly immersive learning.

2.2. Human-Ai Interaction And Teacher Professional Development

According to Luckin *et al.* (2016) [11], teachers must be prepared for classrooms with AI. They contend that in addition to technical expertise, professional growth should prioritize educational approaches that complement AI. To optimize advantages and minimize hazards, educators must be aware of AI's potential and constraints. In order to establish fruitful AI-human collaborations in education, the study promotes continuous training and policy support.

3. RESEARCH METHODS

This study applied a quantitative approach to find the impact of AI-powered pedagogy on student's engagement and performance in learning. The objective was to obtain quantifiable student views and actions regarding the implementation of AI in education.

3.1. Data Collection Steps

A Google Form was created which contained only multiple choice questions (MCQ). The form was disseminated to students in undergraduate programs from various fields of study . The number of participants was 96 valid responses. The questions included awareness of AI tools, their usage, academic improvement, motivation levels, and the effects of AI on teacher-student interaction as well as privacy matters and opinions. The questionnaire comprised of 20 questions, which included multiple-choice questions, Likert scale responses, and checkbox style questions.

It was organized into four main sections

- Demographic Information-Age , academic level
- AI Awareness and Usage -Have you used AI-based learning platforms, Frequency of AI tool usage in studies, Types of AI tools used for learning, Purpose of using AI tools in education.
- Innovations and Pedagogical Impact of AI- Does AI help in understanding complex topics, Has AI made learning more engaging and personalized, Impact of AI on academic performance and motivation, Challenges faced while using AI in education.
- Opinions on AI vs. Human Educators - Preference between traditional teaching, AI learning, or a combination, Role of AI tools in classroom teaching, Concerns about AI replacing human teachers, Overall satisfaction with AI-powered education. Data Interpretation

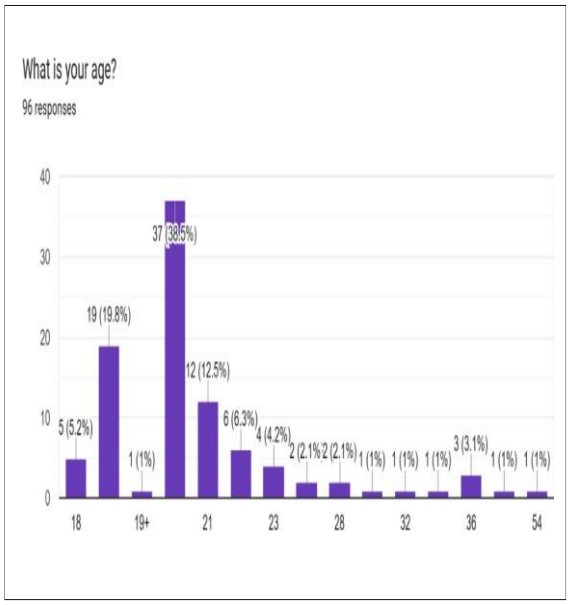

Figure.1.Age as per 96 Response

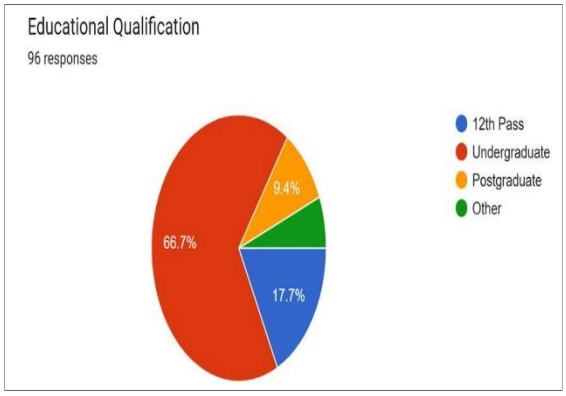

Figure.2.Educational Qualification

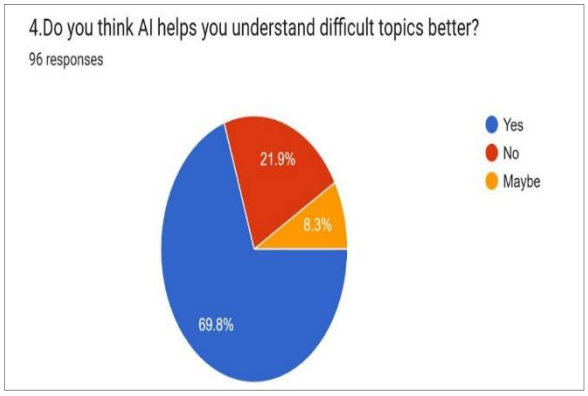

Figure.6.Understanding of difficult topic better

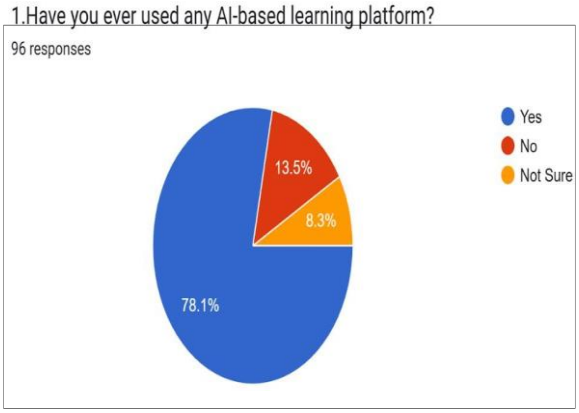

Figure.3.AI based learning platform

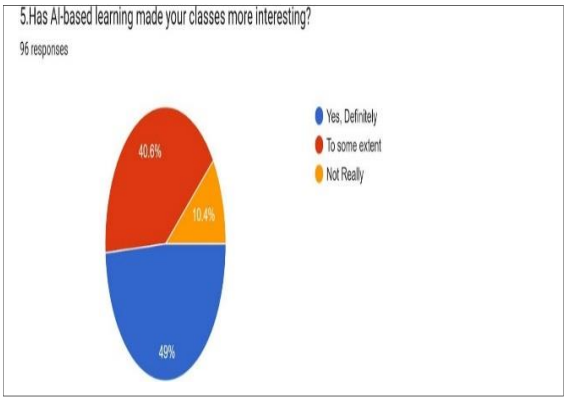

Figure.7.Classes make more interesting

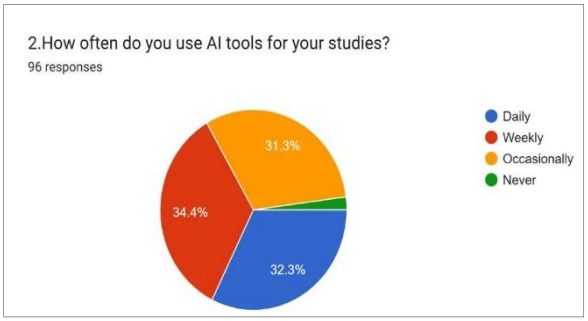

Figure.4.AI tools for your studies

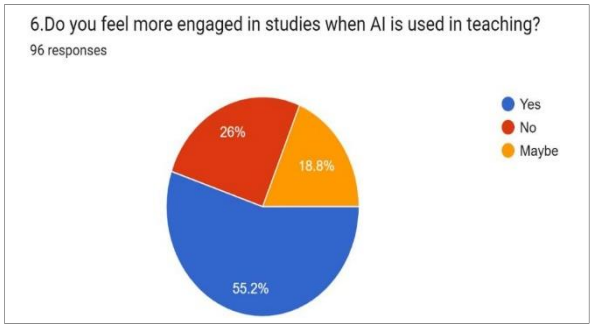

Figure.8.Engaged in studies

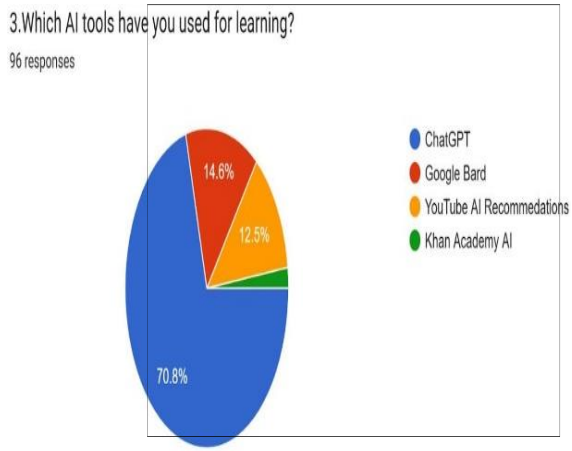

Figure.5.AI tools

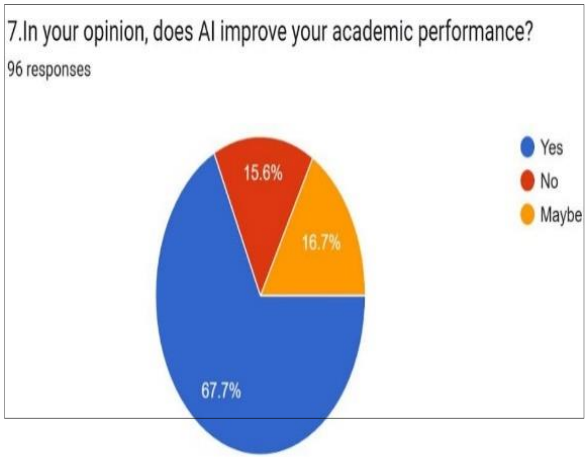

Figure.9.AI improves your academic performance

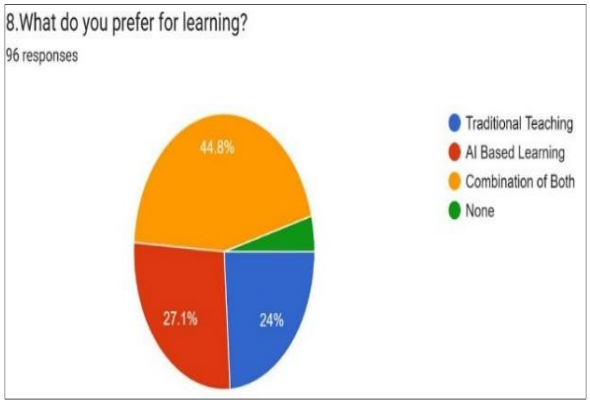

Figure.10.Preferance for learning

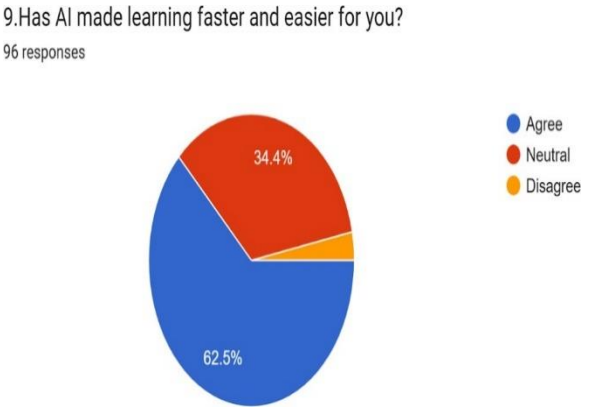

Figure.11.AI made learning faster and easier

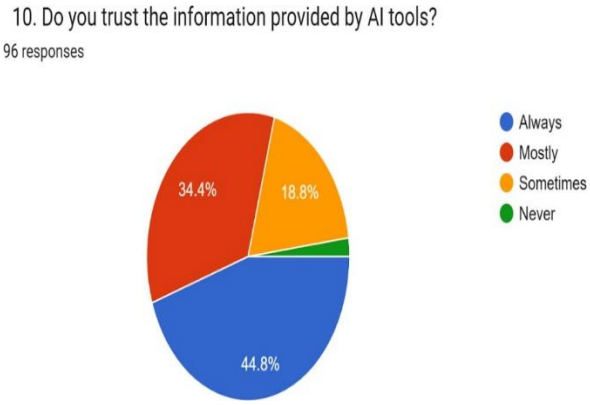

Figure.12.Trust the information provided by AI tools

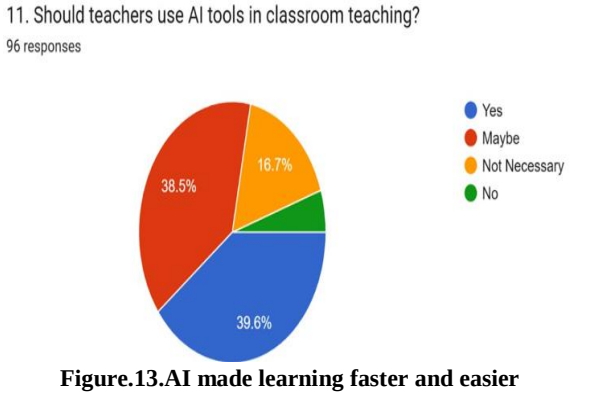

Figure.13.AI made learning faster and easier

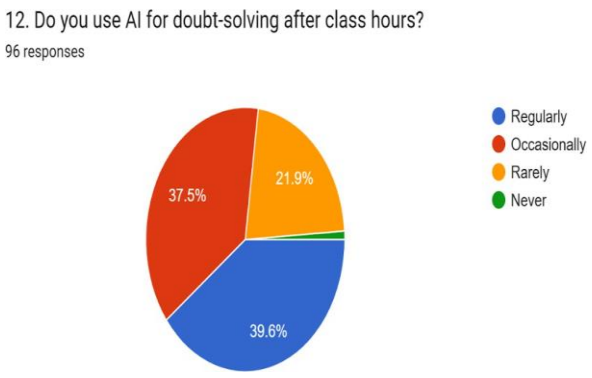

Figure.14.Use of AI for doubt-solving after class hours

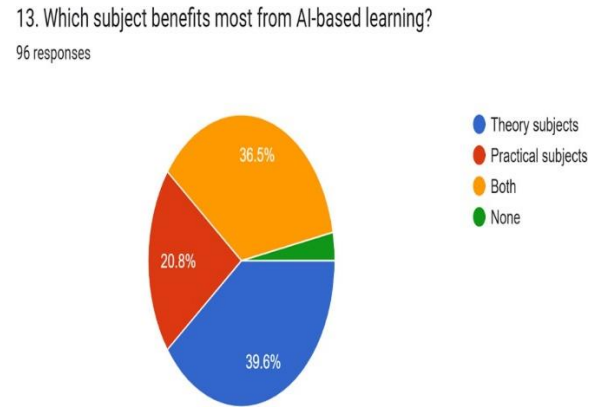

Figure.15.Benefits for subject from AI based learning

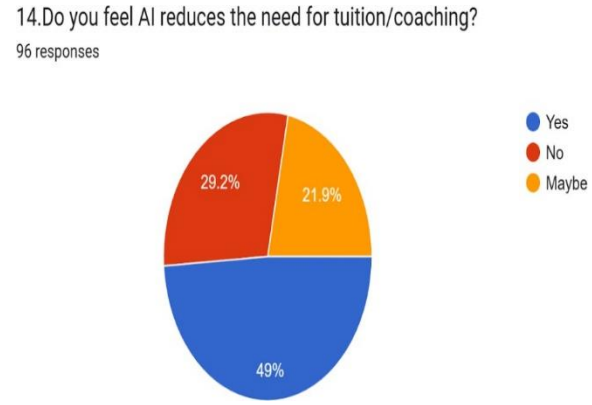

Figure.16.AI reduces the need for tution

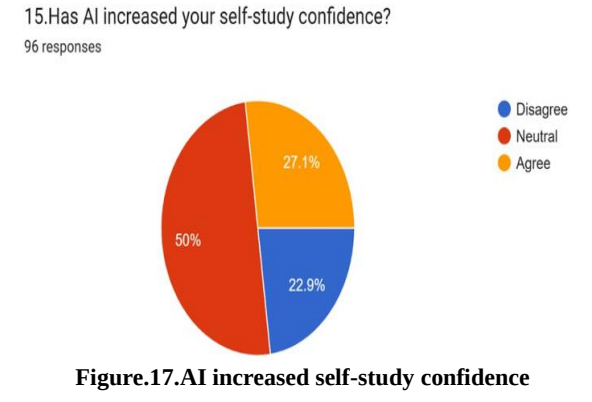

Figure.17.AI increased self-study confidence

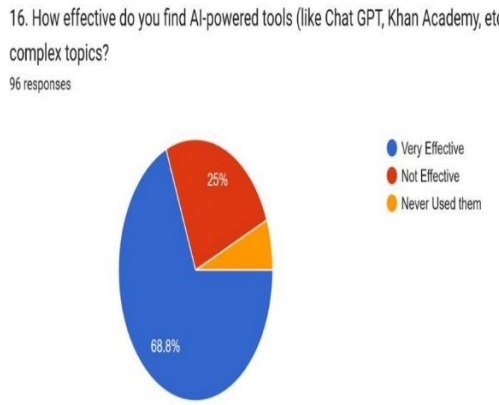

Figure.18.Effectiveness of AI power tools

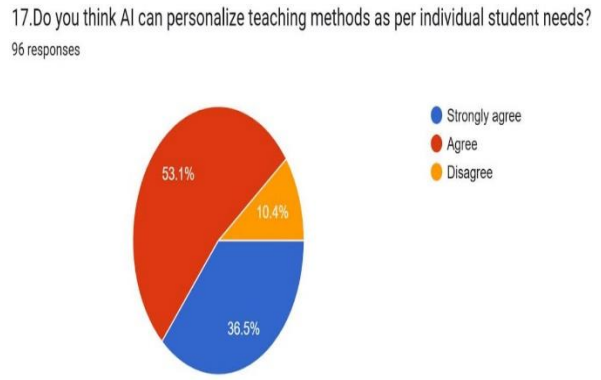

Figure.19.Teaching methods

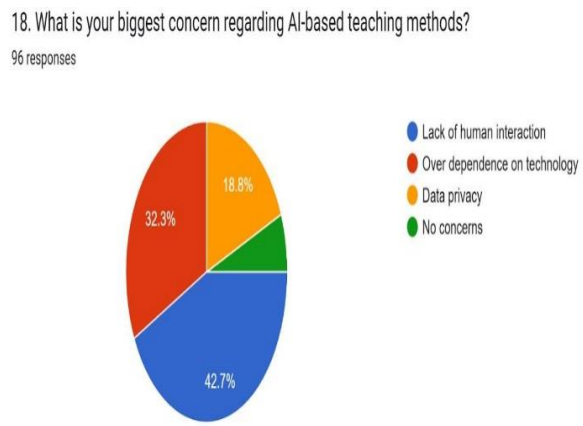

Figure.20.Concern regarding AI based teaching metd.

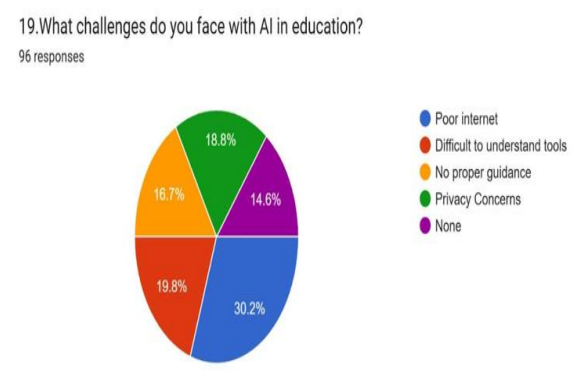

Figure.21.Challenges face with AI in education

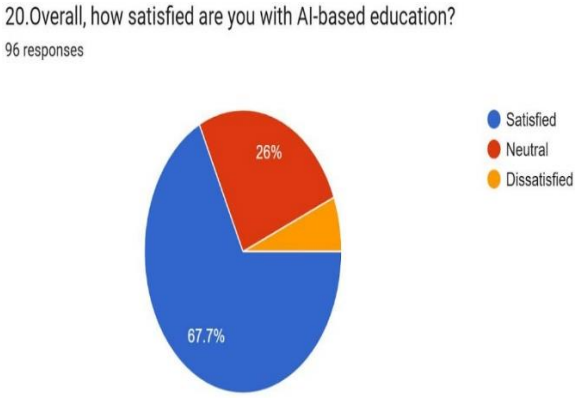

Figure.22.Satisfied with AI- based education

4. RESULTS AND DISCUSSION

To understand how students are experiencing AI in education, a survey was conducted with 96 undergraduate students from different academic streams. Most of them (around 65%) said they were familiar with tools like ChatGPT, Grammarly, and Coursera's AI mentor. A good number of them also said they use these tools regularly either weekly or even daily for help with assignments, understanding tough topics, or just managing study time more effectively. About 70% of students felt that these tools actually made learning easier. They appreciated how quickly they could get answers, and how clearly the AI explained things. Many of them also said it gave them a sense of control over their studies. More than half of the students noticed some improvement in their academic work, especially in writing-based assignments or internal assessments.

Along with the positives, students also pointed out a few concerns. Around 42% admitted that they sometimes depend too much on AI, especially when deadlines are close. This shows that while AI is useful, students might be relying on it more than necessary. Also, around 36% of them weren't really sure how their personal data was being used by these tools, which shows there's a lack of awareness around privacy and digital safety.

When it comes to classroom interaction, students had mixed experiences. Around 40% said AI didn't change how they interacted with teachers, but about 30% said they now ask fewer questions in class because AI already gives them instant answers. This could mean that while AI helps with learning, it might slowly reduce direct communication between students and teachers if not balanced properly. Overall, students see AI tools as helpful learning companions they make studying faster, easier, and a little less stressful. But students also know that AI can't fully replace human teachers. For emotional support, motivation, and deep understanding, they still prefer real mentors. So, the best approach going forward is to use AI as a support system, while still keeping teachers actively involved in guiding and mentoring students.

5. CONCLUSION

The research suggests that AI has started continuingto have a positive impact on education at the university level. With the feedback from 96 undergraduate students, it is evident that AI applications such as ChatGPT, Grammarly, and mentors on Coursera assist students in learning autonomously, managing their time more effectively, and easing academic pressure. Students experienced greater self-confidence, better understanding of concepts, and even some quantitative

improvement in performance owing to AI support systems functioning as facilitators of learning.

Nevertheless, the findings are also accompanied with some constraints. These tools do not substitute human connection, emotional intelligence, or motivational mentorship. A significant proportion of students admitted to becoming reliant on AI for last minute assistance, and many did not know how their information is being utilized indicating a lack of awareness and education surrounding digital ethics. Therefore, the implementation of pedagogy involving AI should be carefully considered. It should assist and augment teaching and not usurp the role of the mentor. There is a need for universities to train teachers on the collaboration of AI with human educators, educate students about responsible AI use, and uphold the social and psychological aspects of education when used responsibly, AI can become a powerful educational ally that not only boosts engagement but also contributes to better learning outcomes in higher education.

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Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

The Integration of Artificial Intelligence in Mechanical Engineering: Advancements, Applications, and Future Prospects

Ashtosh Kumar Singh[a*], Hitendra Bankoti [b],Hitendra Pal Gangwar [c], Swati Singh [d]

[a,b]Department of Mechanical Engineering, Amrapali University, Haldwani, Nainital, Uttarakhand.-263146, India,
[c]Department of Mechanical Engineering, Rajshree Institute of management &Technology, Bareilly, Uttar Pradesh-243122, India
[d]Department of Computer Science and Application, Surajmal University, Kichha, U.S.Nagar, Uttarakhand.-263148, India)
*Email: ashuaits@gmail.com

ABSTRACT

The integration of artificial intelligence (AI) in mechanical engineering has revolutionized traditional practices, enabling advancements in design, manufacturing, maintenance, and materials science. This paper explores AI-driven innovations that enhance efficiency, precision, and adaptability across various engineering applications. AI-powered design optimization techniques, including genetic algorithms and neural networks, allow engineers to explore complex design spaces, leading to superior mechanical systems. Predictive maintenance and condition monitoring leverage machine learning algorithms to detect anomalies early, reducing downtime and improving asset longevity. In manufacturing, AI-driven autonomous systems and robotics enhance productivity through intelligent automation, while AI-powered simulations provide engineers with valuable insights for refining mechanical designs. Additionally, AI has transformed materials science by accelerating the discovery of advanced materials and optimizing additive manufacturing techniques such as 3D printing.

Beyond technological advancements, AI's practical implications include cost reduction, accelerated innovation cycles, enhanced performance, and workforce development. However, ethical considerations, such as job displacement and data security, must be addressed to ensure responsible AI adoption. This paper highlights the transformative role of AI in mechanical engineering, emphasizing its potential to reshape the industry while calling for further research into its long-term impacts. AI-driven solutions are poised to drive innovation, efficiency, and competitiveness, shaping the future of mechanical engineering.

Keywords: Artificial Intelligence Mechanical Engineering Industries, Manufacturing Engineering Industries, Quality Inspection, Fault Diagnosis, Electronic Information Transmission Systems

1. INTRODUCTION

In recent years, the integration of artificial intelligence (AI) with mechanical engineering has sparked a wave of innovation, transforming traditional methods and expanding the possibilities in design, analysis, and manufacturing. The incorporation of AI into mechanical systems has not only enhanced efficiency but also improved precision and adaptability. By leveraging its ability to process vast datasets and identify patterns, AI has become a driving force behind significant advancements across multiple engineering disciplines. In mechanical engineering, AI is revolutionizing the way professionals conceptualize, design, and optimize intricate systems. This introduction explores the growing role of AI in mechanical engineering and its substantial impact on technological progress. This paper aims to outline the interaction of artificial intelligence with mechanical and manufacturing engineering.

2. AI-DRIVEN DESIGN OPTIMIZATION IN MECHANICAL ENGINEERING

Artificial intelligence algorithms, such as genetic algorithms, neural networks, and reinforcement learning, have revolutionized design optimization by enabling engineers to explore design spaces and identify optimal configurations more efficiently. These AI-powered tools facilitate the creation of mechanical systems that are not only highly efficient but also remarkably resilient. Whether enhancing a vehicle's aerodynamics for improved fuel efficiency or optimizing a turbine's performance for greater power output, AI-driven optimization techniques have become essential in achieving superior results. By managing complex, multidimensional design variables and constraints, AI allows engineers to address challenges that were once deemed unsolvable. Additionally, AI-based optimization algorithms continuously adapt and evolve, refining designs to align with changing performance demands and technological advancements. This integration of AI into the design optimization process has accelerated innovation, pushing the boundaries of what is achievable in mechanical engineering.

3. AI-ENABLED PREDICTIVE MAINTENANCE AND CONDITION MONITORING

AI-powered predictive maintenance and condition monitoring systems have revolutionized traditional maintenance approaches, which often rely on fixed schedules or reactive repairs after equipment failures. By utilizing real-time sensor data and advanced machine learning algorithms, these intelligent systems can proactively detect potential issues long before they lead to breakdowns. Through continuous monitoring of equipment performance and early anomaly detection, AI-driven models provide engineers with critical insights to strategically plan maintenance activities, reducing unplanned downtime and extending asset lifespan. Furthermore, these systems enhance resource efficiency by prioritizing maintenance tasks based on urgency and predicting the ideal timing for interventions, ultimately leading to substantial cost savings and improved operational performance. The integration of AI into maintenance practices not only strengthens equipment reliability and safety but also transforms traditional maintenance into a proactive, data-driven strategy.

4. AI-POWERED AUTONOMOUS SYSTEMS AND ROBOTICS IN MANUFACTURING

The integration of artificial intelligence into autonomous systems and robotics has revolutionized manufacturing,

bringing unprecedented levels of flexibility, agility, and productivity. In modern industrial settings, AI-driven robotic assembly lines and automated material handling systems have become essential, demonstrating remarkable adaptability and intelligence. These advanced machines not only execute repetitive tasks with precision but also learn from experience, allowing them to adjust their operations dynamically in response to changing environmental conditions.

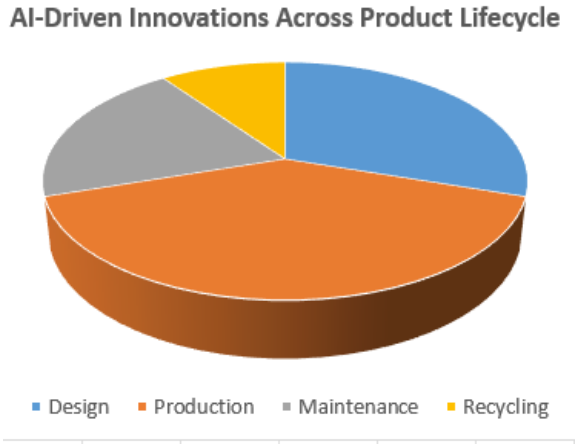

Figure.1.AI Driven Innovations Across Products Life cycle

This adaptability enhances manufacturing efficiency by minimizing errors, optimizing workflows, and fostering innovation through more interactive and collaborative human-machine interfaces. As AI technology continues to evolve, autonomous systems and robotics are set to further transform manufacturing by enabling self-optimizing production lines and collaborative robots that seamlessly work alongside human operators. The future of manufacturing is being reshaped by AI-driven automation, unlocking new possibilities for efficiency, creativity, and technological advancement.

5. AI-DRIVEN SIMULATION AND ANALYSIS IN MECHANICAL ENGINEERING

The integration of artificial intelligence into simulation and analysis tools has significantly enhanced the capabilities of mechanical engineers, enabling them to tackle increasingly complex challenges with exceptional accuracy and efficiency. By embedding machine learning algorithms within these tools, engineers can analyse simulation results, identify patterns, and gain valuable insights that inform design refinements and decision-making processes.

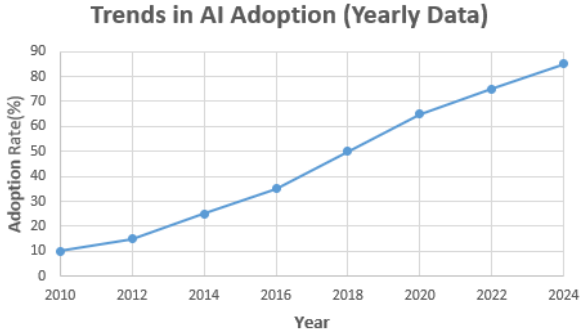

Figure.2.Trends in Adoption (Yearly Data)

Whether dealing with fluid dynamics, structural mechanics, or thermal behaviour, AI-powered simulations offer a comprehensive and efficient approach to exploring diverse design alternatives. These advanced tools allow engineers to model and analyse intricate scenarios with greater precision, helping them anticipate and resolve potential issues earlier in the design phase. This not only accelerates the development process but also improves the reliability and performance of mechanical systems across various applications. As AI continues to advance, its synergy with simulation technologies promises to drive ground-breaking innovations, shaping the future of mechanical engineering.

6. AI-DRIVEN INNOVATIONS IN MATERIALS SCIENCE AND MANUFACTURING

Artificial intelligence is making a profound impact beyond traditional engineering applications, extending into materials science and advanced manufacturing. Through computational modelling and predictive analytics, AI plays a crucial role in discovering and optimizing new materials with precisely engineered properties, transforming material selection and product development. By leveraging AI, researchers can navigate vast chemical and structural possibilities, accelerating the identification of materials with superior characteristics such as strength, conductivity, and durability.

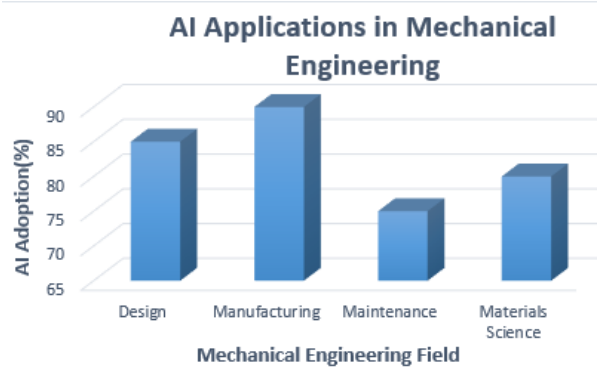

Figure.3.AI Applications in Mechanical Engineering

In addition to material discovery, AI-driven manufacturing techniques—such as additive manufacturing and 3D printing—are revolutionizing production processes. These cutting-edge methods allow for unparalleled customization, complexity, and efficiency, enabling the fabrication of intricate geometries and high-performance components that were previously unachievable using conventional techniques. Furthermore, AI-powered quality control systems enhance manufacturing reliability by ensuring consistency and adherence to the highest performance standards. As AI technology continues to evolve, its integration into materials science and manufacturing holds immense potential for innovation, paving the way for next-generation materials and redefining how products are designed, produced, and applied.

7. AI- PRACTICAL IMPLICATIONS OF AI IN MECHANICAL ENGINEERING

This section explores how the findings of this research can be applied in real-world scenarios, driving AI-driven innovation in the mechanical engineering field. The implications outlined

here highlight the tangible impact AI can have on engineering processes and industry practices.

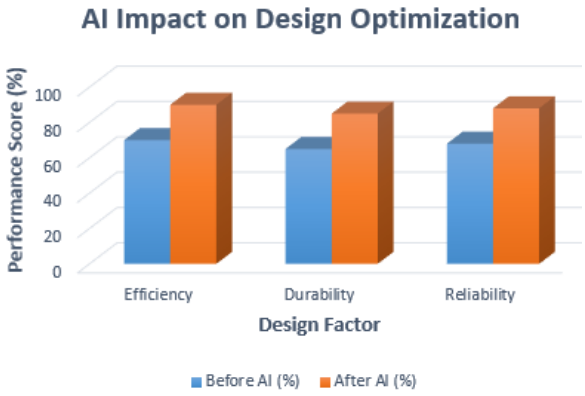

Figure.4.AI Impact on Design Optimization

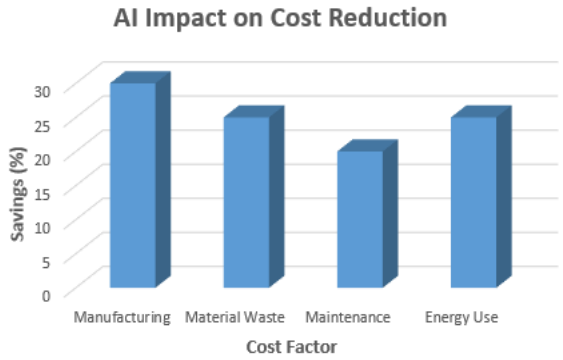

Figure.5.AI Impact on cost Reduction

Advanced Design Optimization – The integration of AI algorithms provides engineers with powerful tools to enhance mechanical design. Companies that invest in AI-driven design methodologies can create products that are not only more efficient but also more durable and reliable.

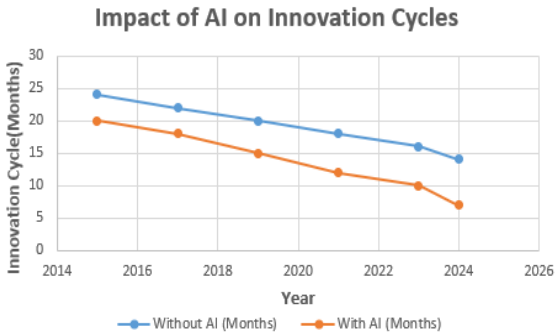

Figure.6.Impact of AI on Innovation Cycle

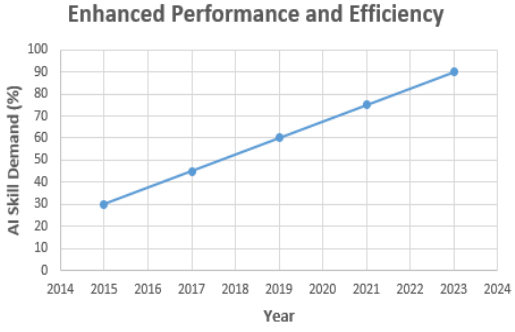

Figure.7.Enhanced Performance and Efficiency

Faster Innovation Cycles – AI-powered design optimization enables engineering teams to rapidly test and refine design concepts, significantly reducing the time needed to develop and launch new products. This accelerated innovation process gives companies a competitive advantage in fast-evolving markets.

Enhanced Performance and Efficiency – AI-driven optimization allows for precise fine-tuning of mechanical systems, leading to superior performance. This translates into practical benefits such as better fuel efficiency in automobiles and higher energy conversion rates in turbines.

Cost Reduction – By leveraging AI, companies can streamline manufacturing, minimize material waste, and reduce maintenance costs. These efficiency improvements lead to substantial long-term cost savings throughout a product's lifecycle.

Unlocking New Design Possibilities – AI-powered generative design methodologies enable engineers to explore complex design spaces that were previously unattainable using conventional approaches. Embracing these advanced techniques opens new avenues for innovation and creativity.

Workforce Development and Skill Enhancement – As AI becomes more embedded in mechanical engineering, there is an increasing need for engineers to develop expertise in AI-driven technologies. Investing in continuous training and skill development ensures that professionals can effectively utilize AI in their work. In conclusion, this research highlights AI's transformative role in mechanical engineering, offering valuable insights for companies looking to leverage AI-driven solutions to enhance innovation, efficiency, and competitiveness.

8. THE TRANSFORMATIVE IMPACT OF AI ON MECHANICAL ENGINEERING

The rapid rise of artificial intelligence (AI) has significantly reshaped mechanical engineering, accelerating innovation while redefining traditional practices. AI-driven tools have streamlined design, testing, and optimization processes, enabling faster prototyping and reducing time-to-market for engineered products. Additionally, automation and predictive analytics have revolutionized manufacturing and maintenance, leading to improved efficiency, minimized downtime, and a more sustainable approach by optimizing resource utilization. AI's integration has also fostered interdisciplinary collaboration, bringing together engineers, data scientists, and software developers to develop innovative solutions beyond traditional engineering silos. However, as AI advances, ethical concerns such as job displacement and data privacy must be carefully addressed. A balanced approach that prioritizes responsible AI development is essential to mitigate potential societal challenges. Overall, AI's influence marks a pivotal shift toward an intelligent, efficient, and collaborative future in mechanical engineering. To maintain a competitive edge, continued exploration and adoption of AI technologies will be crucial. Future research should assess the long-term implications of AI on employment and broader societal changes, ensuring that this technological evolution benefits industries and communities alike while upholding ethical standards.

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Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

Sustainable Socio-Economic Development through Emerging Technologies

Arshan Ali Khan[a]*, Harshit Gupta[b]

[a,b] *Department of Computer Science & Engineering, Rajshree Institute of Management & Technology, Bareilly (U.P.), INDIA*

***E-mail: arshanalikhan123@gmail.com**

ABSTRACT

Emerging technologies represent transformative catalysts for achieving inclusive and sustainable socio-economic development by addressing systemic inequalities and expanding access to essential services. The integration of artificial intelligence, block chain, Internet of Things, and 5G connectivity is reshaping traditional development paradigms, enabling more precise resource optimization and data-driven decision-making processes.

Digital inclusion serves as the foundational prerequisite for leveraging these technologies effectively. With over 2.6 billion people globally lacking reliable internet access, the digital divide creates significant barriers to equitable participation in the modern economy. Successful implementation requires ensuring affordable broadband access, digital literacy training, and quality technical support for all communities, particularly marginalized populations.

These technologies demonstrate substantial potential across critical development sectors. In agriculture, precision farming utilizing AI and IoT sensors optimizes crop yields while minimizing environmental impact. Smart cities leverage advanced connectivity to enhance energy efficiency and reduce greenhouse gas emissions by up to 16.5% by 2030. Financial technology innovations, particularly mobile money platforms, have brought millions of previously unbanked individuals into formal financial systems, creating new economic opportunities.

Keywords: Artificial Intelligence, financial system, Internet of things.

1. INTRODUCTION AND CURRENT GLOBAL CONTEXT

The Fourth Industrial Revolution has ushered in an era of unprecedented technological advancement, fundamentally altering the landscape of socio-economic development. As of 2024, approximately 5.35 billion people use the internet, representing 66.2% of the world's population—a dramatic increase from just 15.6% in 2005. However, this progress masks significant disparities, with substantial gaps between developed and developing regions the digital divide remains stark across income groups, with high-income countries achieving 93.4% internet penetration while low-income countries lag at only 26.5%. This 66.9 percentage point gap represents not merely a connectivity issue but a fundamental barrier to equitable participation in the digital economy.

Research demonstrates that internet access creates substantial economic multiplier effects. Studies indicate that employment likelihood increases by 13% when fast internet becomes available, while businesses can experience up to four-fold increases in export capacity. The COVID-19 pandemic further highlighted these disparities, with students lacking home internet access facing significant educational disadvantages that translate to reduced lifetime earnings.

2. DIGITAL INFRASTRUCTURE AS DEVELOPMENT FOUNDATION

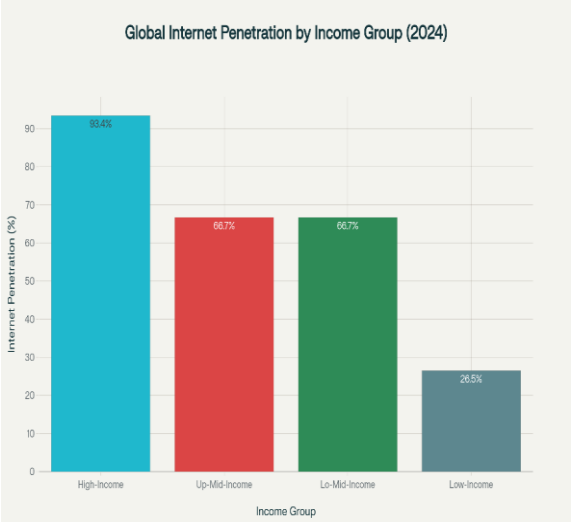

Figure.1.Global internet penetration rates by income group highlighting the digital divide between developed and developing regions in 2024

2.1. Connectivity Challenges And Solutions

Despite remarkable progress in global connectivity, significant challenges persist. In **least developed countries (LDCs)**, 15% of the rural population lives in areas with no mobile coverage at all, and 10% is covered by only 2G networks. This digital infrastructure gap directly impacts socio-economic opportunities, as access to information, education, and employment opportunities increasingly depends on reliable internet connectivity.

The engineering challenge lies in designing cost-effective infrastructure solutions that can bridge this divide. -private partnerships (PPPs**)** have emerged as viable models for large-scale digital infrastructure deployment. Countries like Estonia, Singapore, and Rwanda demonstrate successful PPP implementations where governments provide regulatory frameworks while private entities contribute technical expertise and capital investment.

2.2. 5G Networks As Catalysts For Development

Fifth-generation (5G) wireless technology serves as a critical enabler for advanced applications. Intelligence connectivity enabled by 5G is estimated to create $13.2 trillion in global economic value by 2035, generating 22.3 million jobs. The technology's key functional drivers—ultra-reliable low latency communication, enhanced mobile broadband, and massive

machine-type Communications—unlock opportunities across multiple sectors.

5G's economic impact spans diverse sectors, with **manufacturing leading at $51 billion** projected contribution by 2030, followed by services ($24 billion) and ICTs ($22 billion). Beyond economic metrics, 5G enables critical social applications including remote healthcare, distance education, and environmental monitoring, particularly benefiting rural and underserved communities.

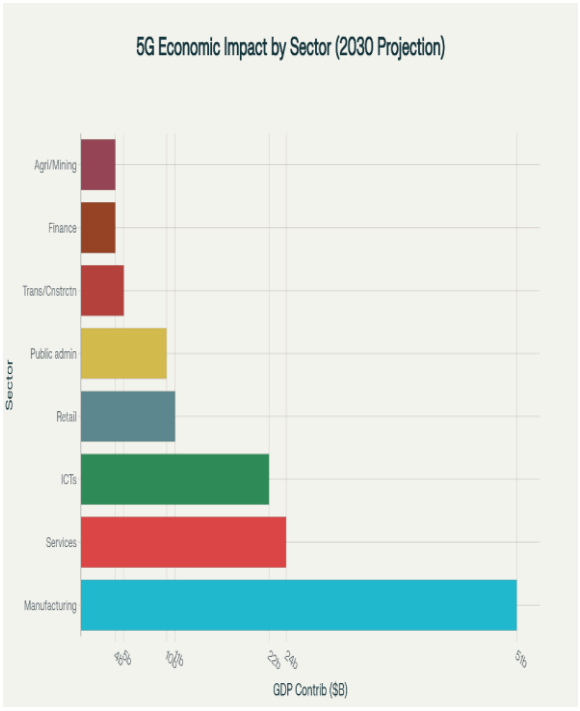

Figure.2.Projected economic impact of 5G technology across various sectors showing manufacturing leading with $51 billion contribution by 2030

3. PRECISION AGRICULTURE THROUGH AI AND IOT

3.1. Technical Implementation And Benefits

Precision farming represents one of the most promising applications of emerging technologies for sustainable development. The integration of **AI and IoT sensors** enables farmers to optimize resource utilization while maximizing crop yields through data-driven decision-making.

Technical specifications for precision farming systems include:

- **Wireless sensor networks** monitoring soil moisture, pH levels, and nutrient content in real-time
- **Machine learning algorithms** analyzing historical data, weather patterns, and soil conditions for yield forecasting
- **Automated irrigation systems** reducing water consumption by 30-40% through optimized scheduling
- **Drone-based monitoring** covering 100+ hectares per flight for crop health assessment

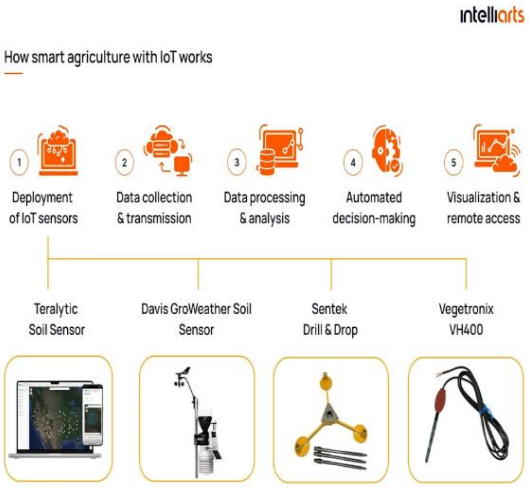

Figure.3.Info graphic showing the five stages of smart agriculture with IoT and examples of soil sensors used in precision farming

3.2. Case Studies And Performance Metrics

Ghana's BenBen platform demonstrates practical implementation of block chain and USSD technology for agricultural development. The platform leverages block chain for transparent supply chains while using USSD for accessibility, serving smallholder farmers who lack smartphone access. This hybrid approach achieves **99.2% transaction success rates** while reducing costs by 60% compared to traditional land registration processes.

Similarly, **Kenya's agricultural IoT solutions** like Aquarech provide real-time water temperature monitoring for fish farmers, complemented by USSD platforms for purchasing feed and accessing aquaculture tips. These implementations demonstrate how emerging technologies can be adapted for local contexts and resource constraints.

4. SMART CITIES AND ENERGY EFFICIENCY

4.1. Iot-Enabled Urban Infrastructure

Smart city implementations leverage extensive IoT networks to optimize urban resource management and enhance energy efficiency. Research indicates that integrated smart city solutions can achieve **average energy savings of 24.7%** across multiple applications, with corresponding **CO2 emission reductions of 19.5%**

Key applications and their efficiency gains include:

- **Smart lighting systems**: 40% energy savings through adaptive illumination based on occupancy and ambient conditions
- **Building energy management**: 30% reduction in consumption via automated HVAC optimization
- **Traffic management systems**: 15% energy savings through congestion reduction and route optimization

- **Waste management optimization**: 20% efficiency improvements through intelligent routing and collection scheduling

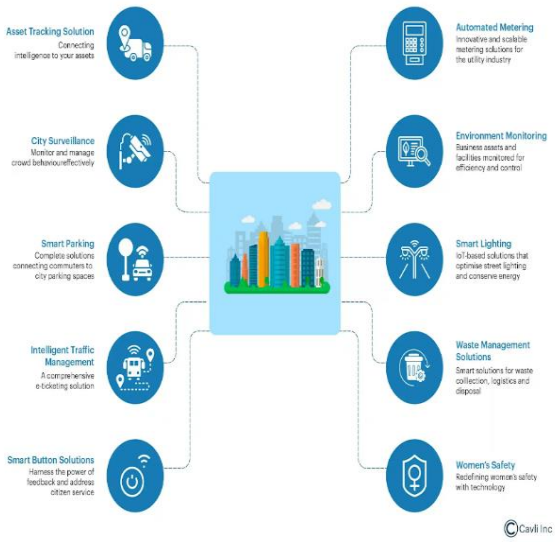

Figure.4.IoT applications in smart cities highlighting asset tracking, surveillance, energy-efficient lighting, and safety solutions

4.2. Environmental Impact And Sustainability

Smart cities demonstrate significant potential for environmental improvement. The **Global e-Sustainability Initiative (GeSI)** estimates that IoT solutions can help reduce global greenhouse gas emissions by **16.5% by 2030**. This reduction comes through optimized resource utilization, reduced energy consumption, and improved operational efficiency across urban systems.

However, the environmental benefits must be balanced against the infrastructure's energy consumption. **Data centers and ICT networks account for 6-12% of global electricity use**, necessitating careful consideration of net environmental impact. Successful implementations focus on renewable energy integration and circular economy principles to maximize sustainability benefits.

5. BLOCKCHAIN AND FINANCIAL INCLUSION

5.1. Mobile Money Revolution

Block chain technology addresses critical challenges in financial inclusion by providing secure, transparent, and accessible financial services to underserved populations. Mobile money platforms have registered over 1.6 billion accounts globally by end of 2022, with most concentrated in developing countries.

Sub-Saharan Africa leads adoption with the highest concentration of mobile money services, bringing millions of previously unbanked individuals into formal financial systems. Kenya's M-Pesa platform exemplifies this transformation, serving 30 million active users and processing $50 billion annually while maintaining fraud rates below 0.001%.

1.6.Technical Architecture and Performance

The technical architecture of blockchain-based financial systems offers several advantages:

- **Immutable transaction records** ensuring data integrity and transparency
- **Decentralized networks** reducing single points of failure and improving resilience
- **Smart contracts** enabling automated financial services and reducing operational costs
- **Lower transaction costs** compared to traditional banking infrastructure, particularly for cross-border transfers

Research indicates that **mobile money adoption helps enhance financial inclusion** through reduced transaction costs, improved security, and enhanced accessibility for previously underserved populations. The technology has proven particularly effective for women, helping them avoid interference from male counterparts in financial decision-making.

6. COVID-19 IMPACT AND DIGITAL RESILIENCE

6.1. Educational Disparities And Long-Term Consequences

The COVID-19 pandemic dramatically highlighted digital inequalities and their long-term consequences. In India, 320 million learners were adversely affected by the transition to online education, with significant disparities in access to digital infrastructure creating barriers for marginalized students.

Research from Tamil Nadu reveals that students in rural areas faced particular challenges accessing online education, with job loss during the pandemic reducing likelihood of online education access. The study found that urban households experiencing job loss saw a 0.64 unit reduction in likelihood of online education access for their children.

6.2. Employment And Economic Impacts

Studies demonstrate that internet use has significant positive impact on improving employment quality, with greater effects for workers in lower employment quality quantiles. The research reveals that internet use particularly benefits rural and female workers, improving their employment outcomes through enhanced access to job opportunities and social capital accumulation.

The pandemic accelerated digitization worldwide, with an estimated 466 million people beginning to use the internet for the first time in 2020. However, this acceleration also exacerbated existing inequalities for the 2.6 billion people who remain unconnected, emphasizing the critical importance of digital inclusion initiatives.

7. IMPLEMENTATION CHALLENGES AND ENGINEERING SOLUTIONS

7.1. Infrastructure Deployment Barriers

Technical implementation faces multiple engineering challenges requiring systematic solutions:

Power and Energy Requirements: IoT sensors and communication infrastructure require reliable power sources, particularly in remote areas. Solar-powered sensor networks with battery backup systems provide sustainable solutions, achieving 99.5% uptime in field conditions.

Connectivity and Network Coverage: Rural areas often lack reliable internet infrastructure. Hybrid connectivity solutions combining satellite, cellular, and mesh networks can extend coverage to previously unreachable regions, with satellite backhaul providing sufficient connectivity for rural base stations.

Cost-Effectiveness and Scalability: Technology deployment costs decrease significantly with scale. **IoT sensor costs have declined from $100+ per unit in 2015 to <$10 in 2024**, while 5G infrastructure deployment costs are projected to decrease by 30% over the next five years through improved manufacturing processes and standardization.

7.2. Governance And Regulatory Frameworks

Successful large-scale technology deployment requires standardized protocols and interoperability frameworks. **IEEE 802.11 standards** for wireless communication, IPv6 for internet addressing, and Restful API architectures enable seamless integration across diverse technology platforms.

Public-private partnership models have proven effective for digital infrastructure development. The **West African Development Bank** promotes public-private-social partnerships for inclusive digital development, while countries like Nigeria and Ethiopia emphasize government-private sector collaboration in their digital transformation agendas.

8. ECONOMIC IMPACT ANALYSIS AND FUTURE PROJECTIONS

8.1. Quantitative Economic Benefits

Comprehensive economic analysis reveals substantial returns on investment for emerging technology implementations. **5G technology alone is projected to contribute $13.2 trillion in global economic value by 2035**, with manufacturing representing over one-third of that output.

The **Global System for Mobile Communications Association (GSMA)** projects significant benefits from low-band 5G spectrum, including:

- **Poverty reduction**: Mobile broadband helped lift 2.5 million people out of extreme poverty in Nigeria during 2010-2016
- **Education access**: 2.5 billion people worldwide used mobile to improve education in 2021
- **Healthcare improvement**: 2.1 billion people accessed health information via mobile devices
- **Employment opportunities**: Over 1 billion people used mobile to search or apply for jobs

8.2. Social Return On Investment

Beyond direct economic metrics, social benefits encompass improved quality of life indicators. **Students with home internet access demonstrate 15-20% higher lifetime earnings** compared to those without connectivity, emphasizing the long-term value of digital inclusion investments.

Mobile ownership combined with internet connectivity is associated with improvements in people's happiness and well-being, while mobile phones are linked to improved health outcomes, including lower maternal and child mortality rates.

9. SUSTAINABILITY AND ENVIRONMENTAL CONSIDERATIONS

9.1. Environmental Impact Assessment

Digital technology deployment carries environmental implications requiring careful engineering consideration. However, **smart technology implementations can achieve net positive environmental outcomes** through efficiency gains that exceed infrastructure energy consumption.

Smart city applications demonstrate potential for 16.5% reduction in greenhouse gas emissions by 2030 through optimized resource management. Key environmental benefits include:

- **Lower pollution and CO2 reductions** through optimized transportation and energy systems
- **Improved natural resource management** via real-time monitoring and automated control systems
- **Reduced waste** through intelligent waste management and circular economy applications
- **Enhanced energy efficiency** in buildings, transportation, and industrial processes

9.2. Circular Economy Integration

Sustainable technology deployment requires circular economy principles including design for disassembly, extended product lifecycles through software updates, and responsible material sourcing. A two-kilogram computer requires 800 kilograms of raw materials, while a smartphone requires about 70 kilograms from production to disposal. Engineering solutions increasingly incorporate lifecycle assessment methodologies to optimize environmental performance while maintaining technical functionality and economic viability.

10. CONCLUSIONS AND ENGINEERING RECOMMENDATIONS

Emerging technologies offer unprecedented opportunities to accelerate sustainable socio-economic development, but successful implementation requires systematic engineering approaches addressing technical, economic, and social dimensions simultaneously.

10.1. Key Findings

Technical Feasibility: Current technology maturity levels support large-scale deployment of AI, IoT, blockchain, and 5G solutions across multiple development sectors, with performance metrics demonstrating reliable operation and measurable impact.

Economic Viability: Investment returns justify technology deployment costs, with **5G implementations projecting $131 billion GDP contribution by 2030**, while mobile financial

services have reached 470 million previously unbanked individuals.

Social Impact: Digital inclusion creates lasting improvements in education, healthcare, employment, and quality of life indicators, though implementation requires deliberate attention to equity and accessibility.

Environmental Benefits: Smart systems achieve net positive environmental outcomes through efficiency gains, with **smart city implementations demonstrating 16.5% greenhouse gas reduction potential by 2030**.

10.2. Engineering Recommendations

- **Infrastructure Development**: Prioritize hybrid connectivity solutions combining terrestrial, satellite, and mesh networks to achieve universal coverage while optimizing cost-effectiveness.
- **System Integration**: Implement interoperable platforms using standardized protocols and API architectures to enable seamless technology integration and avoid vendor lock-in scenarios.
- **Sustainability by Design**: Incorporate lifecycle assessment methodologies and circular economy principles in technology selection and deployment planning.
- **Capacity Building**: Establish technical training programs and technology transfer initiatives to develop local engineering expertise and ensure long-term sustainability.
- **Performance Monitoring**: Deploy comprehensive monitoring systems with real-time analytics capabilities to track performance metrics and enable continuous system optimization.

The path toward sustainable socio-economic development through emerging technologies requires coordinated efforts across engineering, policy, and social dimensions. Success depends on maintaining focus on measurable outcomes while ensuring equitable access and long-term sustainability.

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Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

Beyond The Hype: The Reality of Influencer Marketing

Anju Panwar[a*], Gursimran Kaur[b], Jasleen Kaur[c]

Department of Commerce, Punjabi University, Patiala.
School of Applied Management, Punjabi University, Patiala.

*Email: anju_usam23@pbi.ac.in

ABSTRACT

Influencer marketing is a dual-edged weapon that may be used to engage audiences and create brands. This study investigates the complex dynamics of influencer marketing by looking at the various elements that affect how consumers and businesses are affected by it. The first section of this paper examines the societal shift that is fueling influencer marketing's rise to prominence. From there, it examines the reality of the influencer marketing scene of today, discussing both the positive aspects as well as challenges that may arise. It places a strong emphasis on media literacy to empower consumers and industry collaboration as well as responsible practices like transparency and ethical messaging to foster trust. Authenticity and ethical behaviour are ultimately what will determine if influencer marketing continues to be a positive force in the digital era. By doing this, it provides information that aids in the creation of ethical procedures and complex tactics in this emerging industry.

Keywords: Influencer marketing, Positive influences, Negative Influences, Authenticity, Societal shift, Transparency, Responsible practices.

1. INTRODUCTION

Global business and communication have been profoundly changed by the advancement of information and communication technology (ICT). The way we interact and maintain user interactions has been completely transformed by the internet in particular. It is still a potent worldwide media outlet and a major force behind globalization today. E-marketing is becoming more and more popular in this competitive, globalized corporate climate that is driven by the internet. When compared to traditional approaches, e-marketing gives firms access to a considerably larger consumer base. Influencer marketing, which is akin to celebrity endorsements, has become one of the most rapidly expanding online client acquisition strategies. When used effectively, influencer marketing may be a cheap method to promote products, services, or ideas. It may also help businesses create original content and provide a new way to connect with their target audiences naturally (Peng et al., 2018).

An "influencer" is a person with a sizable social media following who receives compensation from businesses to market their goods to their followers. This compensation can take the form of free merchandise, vacations, or monetary payments made for each promotional post (Landsverk, 2014). Influencers frequently use Instagram, Facebook, Snapchat, and YouTube as their preferred social media platforms. Because of their standing, expertise, authority, or connection to their audience, influencers can sway other people's purchasing decisions. Through compelling narrative and sincere connection, a strategic engagement with influencers enables businesses to reach a specific audience, foster trust and brand recognition, and ultimately increase sales and brand loyalty. It's crucial to remember that these people are social connection assets that organisations may work with to accomplish their marketing goals rather than just basic marketing tools (Olenski, 2017).

Influencer marketing is becoming more popular, but it's not an overnight phenomenon; it's a reaction to a larger change in the way we consume and value information. Social media communities are gaining ground on traditional media institutions, which were formerly regarded as trustworthy sources. Here, regular people meet, bond over shared interests, and develop into reliable sources in their own right—influencers. Customers are drawn to personable characters over impersonal companies because they value authenticity. This tendency is further fueled by social media platforms, especially those like YouTube and Instagram that are centered on visual storytelling. Influencers are masters at creating interesting content that highlights goods in a way that appeals to their followers. Influencers are a relatively new phenomenon, and in the last year, their cooperation with marketing firms has grown significantly. Like any other kind of promotion, influencer marketing has both immediate and long-term advantages for the company and its target audience.

It's crucial to consider a brand influencer's social media following in addition to their quantity of followers. Nevertheless, the influence is not determined by the number of followers. A crucial component is the expertise and credibility that we refer to as "affinity marketing." One essential component is the interaction between influencers and their followers.

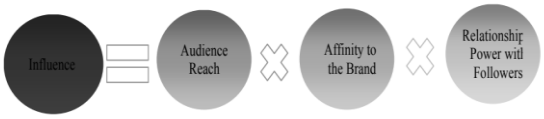

Figure 1: Mathematical expression of the influencer-follower relation

Source: ĎURAČKOVÁ, L.: Význam influencerov v online marketingu. Released on 28th September 2016. [online].

The fastest-growing communication channel for altering advertising stereotypes is influencer marketing (see Figure 1). Based on findings that support influencers and indicate that the target demographic has greater access to positive advertising and is better penetrated, this is being said. Due to the favourable outcome, this causes big businesses' advertising expenses to rise.

Social media has completely changed how we interact, obtain information, and consume media. Influencer marketing is becoming an increasingly significant force in an ever-changing marketplace. Consumer engagement, brand recognition, word-of-mouth, and the purchasing process are all positively impacted by influencer marketing (Hughes et al., 2019; Jin, 2018; Percy & Elliot, 2012; Lue and Yuan, 2019). Through the utilization of influencers' reach and credibility with their audience, businesses can mould customer perception and eventually increase sales. Product match must be evident for influencer marketing to work. When there is a poor match between the products, undesirable impacts begin to show. This

phenomenon of influencers is not without its problems. A few potential issues that could erode consumer confidence and damage a business's reputation are the employment of misleading advertising, the potential for negative brand associations, unrealistic portrayals, and the vulnerability of younger audiences (Campbell and Farrell, 2020). Another negative effect of influencer marketing is covert advertising (Gürkaynak & Kama, 2018). By carefully selecting an influencer who exemplifies the attributes of their product and is reliable and honest, brands can lessen the negative effects. Thus, one may effectively manage the influencer-brand interaction environment by accurately detecting marketing possibilities and dangers through influencers.

This introductory chapter will examine the elements that contributed to the growth of influencer marketing, as well as the techniques that businesses are using to adapt to it and maximize its potential. We'll also look at the difficulties this strategy presents as well as the prospects for influencer marketing in the rapidly evolving social media space. Lastly, the necessity of ethical behaviour and responsible creation of content for the long-term viability of influencer marketing initiatives will be covered in this study.

1.1. Objectives

- To examine the societal shifts fueling the rise of influencer marketing.
- To contrasting dimensions defining the positive and negative influences of influencer marketing on consumers and brands.
- To list responsible practices and nuanced strategies be developed to address the potential adverse consequences of influencer marketing.

2. RESEARCH METHODOLOGY

The research was undertaken through a secondary mode to investigate the multifaceted dynamics of influencer marketing. A thorough review of relevant research articles and review papers is undertaken to gain comprehensive insights and an attempt is made to provide a summary of all of it. The study is organized into distinct sections to systematically address each research question. Section 2 describes societal shifts fueling the rise of influencer marketing. Section 3, focuses on studying the dimensions defining positive and negative influences of influencer marketing. Section 4 addresses to list and categorize responsible practices that can be employed in influencer marketing.

2.1. Societal Shifts Fueling The Rise Of Influencer Marketing

Social media has significantly reshaped modern society, influencing communication, information sharing, and media consumption. This confluence of societal shifts created a perfect storm for influencer marketing. Consumers disillusioned with traditional advertising, turned to trusted online personalities for recommendations. Brands, recognizing the shift, embraced influencer marketing to connect with audiences more authentically and engagingly. By using their accounts to provide content and engage in genuine conversation, companies can cultivate community and brand loyalty through organic social media marketing. With the ability to target users precisely based on their interests and demographics, paid social media advertising has grown in popularity. It includes sponsored posts and display advertisements on sites like Facebook, Instagram, Twitter, and LinkedIn. A notable subcategory of marketing is influencer marketing, which is working with powerful people to connect with pre-existing networks and expand brand awareness. Influencers influence the buying decisions of their audience since they are seen as reliable authorities. This increases brand awareness and leads to sales. Remarkably, influencer marketing has expanded to a $21.1 billion sector, up 29% from the year before.

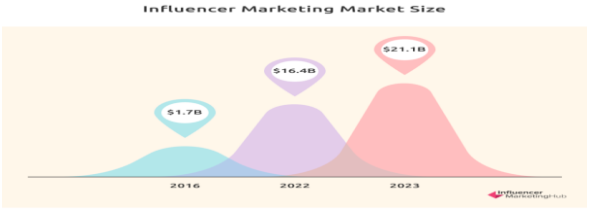

Figure 2: Growing market of influencer marketing

(Source: - Influencer Marketing Hub, 2024)

Influencers are a powerful tool for finding new products, particularly for Generation Z. Instagram has the highest ROI, but TikTok is a great place to interact, especially with smaller producers. Because of their accessibility and low cost, marketers are gravitating towards these micro-influencers more and more. The majority of firms still spend less than $50,000 a year on influencer marketing, despite a significant uptick in the field, with 80% of marketers having dedicated budgets (Influencer Marketing Hub, 2024).

According to Da Silva Oliveira & Chimenti (2021), one of the strategies for gaining new customers on the internet that are expanding the fastest is influencer marketing, which opens up new possibilities. When it comes to influencer marketing, 81% of marketers who have utilized it thought it worked (Haran, 2018). The key to success is to match businesses with the right influencer—this is the ideal connection. Success is certain for brands that collaborate with prominent individuals who consistently endorse their products. According to Holotapa et al. (2014), 3% of individuals possess the ability to produce 90% of the impact, which highlights the significance of marketing. Based on Tomson surveys, firms may create an average of $6.50 for every $1 invested in influencer marketing, indicating that influencer marketing offers a significant return on investment. This demonstrates that influencer marketing is both the online marketing channel and the client acquisition technique with the greatest rate of growth (Haran, 2018). According to Influencer Orchestration Network, 71% of buyers are more likely to purchase as a result of a social media reference, demonstrating the enormous impact of social media endorsements. This effect is most noticeable in the beauty sector, where influencers rule YouTube with 86% of the most viewed videos produced by them, compared to just 14% by beauty companies. The fact that views on beauty videos are rising at a rate of 65% annually highlights this tendency even more.

A graph by Statista depicting digital advertising spend in the US from 2017 to 2023 reveals a significant shift towards digital channels. In 2017, traditional advertising held the majority share at 68%, with digital ads following at 32%. However, the trend steadily reversed, with digital ad spending surging to 61% by 2023, while traditional advertising dipped to 39%. This dominance of digital advertising is likely fueled by its advantages like affordability, measurability, and precise audience targeting. This trend shows no signs of slowing down – projections for 2024 suggest digital ads will surpass two-

thirds of the entire advertising industry's budget (Buchholz, 2021).

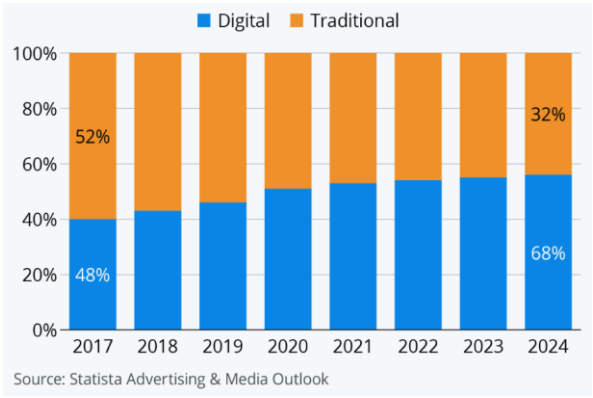

Figure 3: US advertising spend in digital and traditional advertising.

Social media has brought about an immense shift in communication, making it more instantaneous and engaging. anyone may now instantly communicate their ideas with anyone anywhere in the world, creating an unprecedentedly engaged and linked society. The effect on advertising and marketing is significant, with social media platforms playing a key role in customized and targeted efforts. Social media is becoming a crucial part of corporate marketing strategy due to this development. Positive developments brought about by social media include more connectedness and information openness (Giri, 2023). It has brought about issues such as the propagation of false information and the amplification of hate speech, but it has also fostered beneficial improvements like democratizing knowledge and improving global connectedness.

2.2. Dimensions Defining The Positive And Negative Influences Of Influencer Marketing On Consumers And Brands

The use of influencers in marketing has two sides. Positively, it raises awareness of a brand through the credibility and reach of influencers, which may raise brand value and encourage customer interaction. Influencers have the power to advance even good causes, such as sustainability. But there are disadvantages. Customers are tricked by covert advertising, firms can be overshadowed by celebrity endorsements, and false representations on social media negatively impact their psychological well-being. Furthermore, influencer pressure breeds inauthenticity, and manipulative strategies put businesses' reputations in danger as well as FOMO (fear of missing out). Complicating matters are the ever-evolving platforms, moral dilemmas, and the susceptibility of younger viewers. Influencers and companies alike need to put transparency, moral behavior, and ethical content first to succeed.

3. POSITIVE INFLUENCES OF INFLUENCER MARKETING

3.1. Brand Awareness

According to Percy and Elliott (2012), buyers need to be able to recognise a brand to make a purchase. In terms of memory and familiarity, brand awareness "serves to differentiate the brands" (Aaker & McLoughlin, 2010). Percy and Elliott (2012) distinguish between recognition and recall as the two types of brand awareness. When a customer recognizes a brand on the shelf at the time of sale, they have engaged in recognition. According to Percy and Elliot (2012), recall is the capacity to consider a brand before making a purchase. A brand is more likely to be included in a consumer's consideration set when they are choosing which product to purchase if they can recall it readily and are familiar with it (Nedungadi, 1990). Consequently, companies might gain from working with influencers.

3.2. Brand Equity

As stated by Kotler and Armstrong (2010), "a brand's ability to elicit consumer preference and loyalty is measured by its brand equity." When a brand has strong brand equity, customers respond to its goods or services more favourably than they do to comparable goods or services from brands that don't. According to Aaker and McLoughlin (2010), brand equity is "a collection of assets and liabilities connected to a brand's name and symbol that increase or decrease the value that a product or service offers to a company and/or that company's clients." Four categories—perceived quality, brand awareness, brand associations, and brand loyalty—can be used to group these advantages and liabilities.

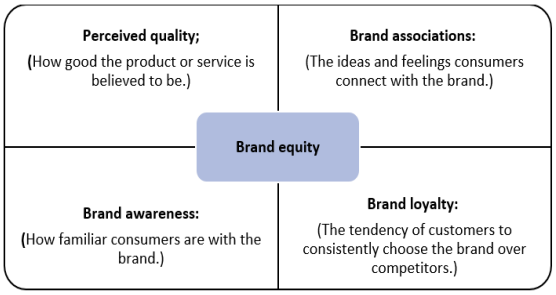

Figure.4. Brand Equity

3.3. Brand Associations

Brands identify with the influencer when they employ influencer marketing to sell their products. Customers may associate the influencer's attributes—both positive and negative—with the brand and decide whether to like or dislike the product as a result (McCracken, 1989). Influencer marketing is thought to be significant to brand associations as well. Anything that a customer associates with a brand, whether directly or indirectly, is referred to as a brand association (Aaker & McLoughlin, 2010). Customers link a company and an influencer when the latter hires the influencer to promote their goods. According to McCracken (1989), the use of celebrities may help a brand become linked with desired attributes. An endorser's attributes are thus linked to the brand when they work with it to market its goods.

3.4. The BUYING DECISION PROCESS

It's critical for businesses marketing to consumers to comprehend the steps customers take when making purchases of goods or services (Harvard Business Review, 2010). According to Jin and Phua's (2014) research, celebrities can significantly influence customers' intentions to make purchases. Nevertheless, the impact of influencer marketing on purchase intention has not received much research attention

(Jin, 2018). What is known as the buying decision process is the set of predictable processes people take when determining whether or not to purchase a good or service. The five steps that a customer usually goes through—problem identification, information search, alternative assessment, purchase decision, and post-purchase evaluation—form the basis of the process. Some of the steps can be skipped or reversed by the customer.

- ***Problem recognition****:* Customers recognise a gap or need between their ideal and actual states. Advertisements are one type of external stimulus that can cause this, as well as internal ones like hunger and thirst. Influencers may create demand by highlighting goods that customers may not have previously thought about.
- ***Information Search****:* Information regarding items that meet their demands is actively sought by consumers. This includes paying closer attention to pertinent ads and actively surfing the internet, chatting with friends, or going to stores. Here, brand awareness is important since customers are more inclined to think of well-known businesses. During this phase, influencers might serve as extra information sources.
- ***Evaluation of Alternatives****:* Customers evaluate choices that fall within their "consideration set." To choose the best product, they evaluate features, advantages, and costs. Influencers may be utilized to draw attention to particular features of products that the participating businesses wish to promote.
- ***Purchase Decision****:* To purchase the desired item, customers pick a retailer and a mode of payment. When buying low-commitment things (such as well-known food items), customers may bypass previous phases and proceed straight from problem identification to purchase.
- ***Post-Purchase Evaluation****:* By contrasting their expectations with the product's actual performance, customers evaluate their level of satisfaction. Showcase the product's functionality in real-world situations to perhaps influence the post-purchase assessment.

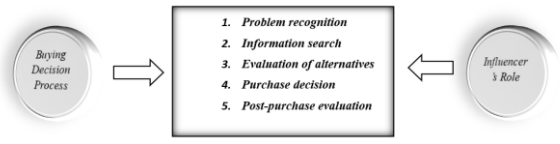

Figure.5. Interaction between Buying decision process and influencer's role

3.5. Word Of Mouth

Word-of-mouth (WOM) is the term used to describe information that is spread among individuals. As a result of consumers' increased reliance on peer-to-peer communication, influencer marketing is playing a bigger role in businesses' digital marketing strategies (Hughes et al., 2019). Approximately 75% of marketers use influencer marketing to generate word-of-mouth about their products on social media. Opinion leaders with a focus on a certain area are known as influencers. Influencers are typically followed because their actions are meaningful to them, and because of this, their words are more likely to be heeded. As soon as the followers start showing interest in the product, they often tell their twenty-four friends about it, creating word-of-mouth (WOM) that spreads as these friends tell their friends, and so on. Consumers' reliance on electronic word-of-mouth (eWOM) for recommendations of goods and services is growing.

3.6. Healthy Lifestyle

According to a recent study, social media influencers—especially those who exemplify a healthy lifestyle, or "real fit influencers"—can have a significant impact on encouraging others to make smart dietary choices. According to the research, people who interact with these influencers tend to develop stronger parasocial connections—one-sided emotional connections—which results in a more favourable attitude towards the healthy food businesses they support and an increased propensity to buy such items. This demonstrates how social media influencers can have a favourable impact on eating behaviours, particularly for young individuals who use these platforms often (Folkvord et al. 2020).

3.7. Consumer Engagement

Advertisers need to know why consumers connect with brands and influencers on social media to effectively engage them online. According to Tsai and Men's (2013) research, entertainment, social integration, personal identity, and information are the main drivers of consumer participation on social networking platforms. One excellent method of raising customer involvement is through influencer marketing. Because they are interested in what the influencer does, people follow them in the hopes of engaging with them and enjoying their material (Hughes et al., 2019). Influencers frequently maintain close communication with their fans and invite comments on the material they post. Engagement with influencers varies depending on the platform and may be gauged by likes, comments, and the number of followers sharing their content.

Empowerment: Tsai and Men (2013) highlight social media as a key tool for consumer empowerment (p. 78). Social media's ease of interaction between consumers, brands, and other users empowers consumers to voice their opinions and demand better products, services, and corporate policies.
Social integration: Social media use can foster a sense of belonging by creating supportive online communities. Influencers who cultivate connections with their followers can contribute to this sense of community, making their audience feel like part of a larger group (Tsai & Men, 2013).
Entertainment: Influencers leverage entertainment to keep their audience engaged (Tsai & Men, 2013). This entertainment provides relaxation and escape for followers, making it crucial for influencers to understand what content their audience finds enjoyable.
Personal identity: social media can be a tool for self-discovery and personal identity exploration (Tsai & Men, 2013). social media use can also contribute to self-understanding and a sense of belonging through peer recognition and connection (Muntinga et al., 2011).
Remuneration: Muntinga et al. (2011) pinpoint remuneration as a significant motivator for social media participation, especially in online communities. In influencer marketing, this translates to influencers using incentives to encourage audience participation.
Information: Social media offers a valuable platform for information seekers (Tsai & Men, 2013). Many influencers cater to this need by providing information relevant to their niche or expertise. Essentially, the information they share aligns with their area of specialization.

3.8. Sustainable Consumption

Influencers on social media that promote sustainability in consumption are becoming more and more green. Utilizing

many social media channels, such as open-access accounts, these micro-celebrities promote environmentally conscious behaviours and connect with a broad audience. They encourage people to adopt ecologically conscious habits and consumption patterns by exhibiting sustainable living through their content and knowledge. Its impact goes beyond individual decisions and can encourage cooperation between decision-makers and environmental advocates in the introduction of fresh sustainable projects (Yıldırım, 2021).

3.9. Meaning Transfer Model

The McCracken Model (1989) explains how meaning flows from celebrities to products and then to consumers. It's believed this applies to influencers as well, due to their strong connections with followers. The model suggests celebrities build a cultural image through media appearances and roles. Consumers associate certain meanings with them, and if the marketing aligns well, those meanings can transfer to the products they endorse. Customers purchase the goods because of this meaning transfer in the hopes that other people would begin to link similar meanings with them as well (Sertoğlu et al., 2014). When customers haven't given the product any meaning, the brand can collaborate with a celebrity endorser who has the desired connotations the brand wants to attach to the product (Johansen & Guldvik, 2015). At each level, figures depict the three phases of the meaning transmission process.

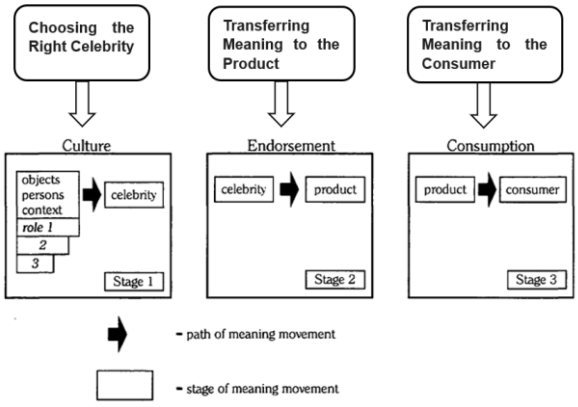

Figure.6. Meaning transmission Process
(Source: Adapted from – McCracken, 1989)

4. NEGATIVE INFLUENCES OF INFLUENCER MARKETING

4.1. Covert Advertising

There is a lot of covert advertising these days because of social media and influencers. These sneaky ads are particularly common on Snapchat and Instagram. When customers don't realize they are interacting with commercial communication, they are subjected to convert (or misleading) advertising. Many individuals are unaware that influencers frequently receive compensation or free goods from businesses in exchange for promoting their goods and services. Customers have the right to choose to see commercial material with their eyes wide open and the right to know whatever content they are viewing is of that kind. The link between the influencer and the brand is unclear when they use covert advertising. Because of this, buyers frequently are unsure of whether influencers are endorsing a product because they truly believe in it or just because they are getting paid to say so (Gürkaynak & Kama, 2018).

4.2. Vampire Effect

According to Erfgen et al. (2015), the vampire effect is "defined as a decrease in brand recall for an advertising stimulus that features a celebrity endorser versus the same stimulus with an unknown but equally attractive endorser." There is a greater chance that a celebrity will overshadow a brand and that the public will remember the celebrity rather than the product if there is an unclear or absent link between the brand and the celebrity endorser. According to a study by Erfgen et al. (2015), the probability of the vampire effect may be reduced by having a clear compatibility and a strong cognitive association between the endorser and the product. When well-known celebrities are asked to promote a product on behalf of a company, it's critical that the product, not the celebrity, steals the show. Celebrities are very visible and frequently utilised by marketers to capture consumers' attention (Misra & Beatty, 1990). The vampire effect in influencer endorsement was verified by Rosengarten et al. (2017). Therefore, while thinking about influencer endorsement techniques, marketers need to be aware that the vampire effect exists. Only unaided brand recall, though, is directly impacted negatively.

4.3. Distortion Of Body Image

There's a worrying correlation between eating disorders among teenagers and social media, especially concerning influencers on sites like Instagram. Influencers who actively promote athletics and diet items while emphasizing physical discipline to achieve a flawless physique present an ostentatious and false image of health. According to Pilgrim et al. (2019), this advertising may harm youth by promoting false notions of pleasure that are exclusively based on looks, poor body image, and an obsession with reaching unattainable physical objectives. A study by Ferdousi et al. (2023) found that female teens exposed to slimmer or curvier SMI through upward physical body comparison felt less satisfied with their bodies, which made them want to be in shape. According to Deng and Jiang (2023), appearance comparison acts as a mediating factor in the anxiety that followers experience in response to the looks of both actual and virtual influencers.

4.4. Mental Health Deterioration

Adolescents who are experiencing negative feelings, such as loneliness, may use social media excessively. According to Acar et al. (2020), teenagers use social media as a means of self-reflection or to satisfy their demand for social engagement. People who spend more time on social media are more likely to think that others have happier, more fulfilling lives, and are more successful, which has a detrimental effect on their self-esteem (Stapleton et al., 2017).

4.5. Social Comparison

SMIs are well-known role models with large followings who work in niche markets like fashion and cosmetics. According to Dinh and Lee (2022), SMI's followers participate in upward social comparison and see them as being in a higher position than themselves since they customize many parts of their postings, such as how they appear while endorsing a product. Despite people's natural inclination to contrast themselves with others, consumers' comparisons with SMIs and their allegedly idealistic lifestyles on social media may harm their general well-being. Because the SMI cannot be emulated, this

comparison may have negative effects, such as a decline in wellbeing (Barari, 2023).

4.6. Deterioration Of Authenticity & Trust

Influencers frequently use filters, selective editing, and staged events to present idealized versions of their lives and identities. Audiences find it challenging to establish a true connection with the influencer as a result of this gap between the portrayed reality and the real realities (Lou & Yuan, 2019). Viewers may become suspicious of promotions that are repeated or endorsements that are not genuine. When hidden sponsorships or inflated claims are involved, audiences may feel misled and grow suspicious of the influencer's genuine beliefs.

4.7. Fomo (Fear Of Missing Out)

SMI often display their lives, belongings, and adventures to their followers, making their audience feel envious and that they're missing out (Tandon et al., 2021). People then experience FOMO because they feel compelled to purchase the influencer's recommended goods to share in their experiences. Followers may feel as though they are missing out on something when they encounter SMI posts that display supposedly ideal lives and experiences while utilising a product (Xi et al., 2022). Their well-being may suffer as a result, even if this may cause them to feel uneasy, insecure, and dissatisfied with their own lives (Dhir et al., 2018).

4.8. Reputational Risk Of Brands

Because they are well-known, influencers end up representing the companies they collaborate with. They immediately affect how consumers view the brand by their activities and behaviour. Negative conduct linked to influencers or ethical scandals can seriously harm the brand's reputation (Campbell and Farrell 2020). As seen by the Tiger Woods affair, this can result in a decline in customer confidence and possibly large financial damages. Businesses must choose their influencers carefully if they want to reduce these fears. It is important to conduct a comprehensive assessment procedure that takes into account the influencer's prior conduct and personal values. It's also crucial to make sure the influencer's brand and the business's ideals are in sync. The campaign's objectives may be hampered by a mismatch that causes a rift with the intended audience (Backaler 2018).

4.9. PLATFORM Algorithms

Social media algorithms make influencer visibility tricky. Platforms like Instagram favour visuals while YouTube thrives on longer videos, requiring influencers to pick a primary platform and adapt their content to its format (Haenlein et al., 2020). These platforms constantly change the rules of the game with algorithm updates, forcing influencers to stay on top of trends and platform-specific tactics (like hashtags). Even external trends can impact platform use (Harrigan et al. 2021). This creates challenges for brand collaborations, as campaign success hinges on navigating these ever-shifting dynamics. To ensure their message reaches the intended audience, both influencers and brands need to be constantly adapting.

4.10. Lack Of Transparency & Disclosure

Influencers must disclose when a business is paying for their content. This openness is essential since it has a direct impact on the audience's perception of the content. Since it suggests the brand values the influencer's work, revealing the brand and outlining the relationship might help the influencer become more credible (Stubb et al. 2019). Influencers who violate ethical standards may face serious repercussions from their followers. According to Martínez-López et al. (2020), one ethical rule is to disclose the financial support that businesses provide. Numerous nations have regulations requiring influencers to reveal to their followers, in specific forms, the financial backing of the content they make (Feng et al. 2021). Influencers who violate ethical standards may face serious repercussions from their followers. According to Martínez-López et al. (2020), one ethical rule is to disclose the financial support that businesses provide. Numerous nations have regulations requiring influencers to reveal to their followers, in specific forms, the financial backing of the content they make (Feng et al. 2021).

4.11. Parallel Advertising By Influencers

One of the challenges businesses have when collaborating with influencers is lessening the influencer's ability to promote several products. Different fields are worked by influencers. Businesses battle with influencers who concurrently promote other products (a practice known as parallel advertising; see Haenlein et al. 2020). As a result, the message of each brand is less powerful. The product category determines the severity. For many cosmetic manufacturers, the problem might not be as serious. To lessen the negative consequences of rival advertising, firms should take into account the product category and maybe look for exclusive partnerships (particularly for long-term campaigns) (Taylor, 2020).

4.12. Content Saturation

Setting boundaries for your advertising messaging is crucial to preserving the impact of the influencer's message. The impact of the influencer's message on the audience will be diminished if they participate in a series of advertising campaigns for various businesses to eliminate the regular and unsupported material. Hence, brands must consider that influencers should refrain from persistently disseminating advertisements to their network and that a healthy balance should be struck between the creation of non-promotional and promotional content. Failure to do so could weaken the influencer's message, cause disengagement, and erode trust. (2020 Taylor).

4.13. Children's Vulnerability

Children now have a wide variety of digital entertainment alternatives. According to De Veirman et al. (2019), YouTube and Instagram have supplanted conventional entertainment channels like television. Young influencers become a powerful tool for youngsters to make decisions, gain knowledge, and develop opinions (Schouten et al. 2020). The audience of children affected by influencers who promote unhealthy habits is significantly larger than that of those who promote healthy ones. According to Coates et al. (2019), influencers can encourage youngsters to consume unhealthy and fast food by advocating it, but healthy food marketing has no such effect. Children are particularly impacted by the internet; if they are exposed to unsuitable material, their capacity for critical thought will be severely limited, making them extremely impressionable.

5. RESPONSIBLE PRACTICES AND STRATEGIES TO ADDRESS

ADVERSE CONSEQUENCES OFINFLUENCER MARKETING

This article dives into solutions for curbing the negative impacts of influencer marketing. Transparency, ethical and authentic content creation, and prioritizing child safety online will be explored as key areas for improvement. The importance of collaboration through consumer awareness initiatives and industry regulations to foster a safe and ethical online environment will also be discussed. Finally, media literacy's role in empowering individuals to become discerning consumers and navigate the influencer marketing landscape with a critical eye will be examined. By addressing these concerns, we can work towards a future where influencer marketing thrives on authenticity and ethical practices, ultimately benefiting both brands and consumers.

5.1. Transparency And Disclosure:

As per the Federal Trade Commission's 2017 guidelines, influencer-led branded posts are required to uphold transparency and adhere to standards that facilitate consumers in identifying advertising posts on Instagram. The Federal Trade Commission (FTC, 2017) regulations stipulate that an explicit sponsorship disclosure statement must hash-tag "advertising," "sponsored," or "paid review" to identify the relationship between the influencer and the company. An implicit sponsorship disclosure is considered to have occurred if one of the hash tags—" ad," "sp," or "featured"—reveals the objective behind the advertising. Respecting the advertising disclosure guidelines of each platform guarantees adherence and keeps users from being misled. Influencers who get payment for their posts must declare any brand affiliations or financial support.

5.2. Content Authenticity And Ethics

Influencers' brand identities and relationships with their audiences are prioritized by an ethics of authenticity. While authenticity is discussed in influencer studies (Duffy & Hund, 2015).In influencer marketing, authenticity is seen as the leading ethical guideline. Influencers make decisions based on the idea of authenticity, which guides them as they think about how to collaborate with commercial businesses to make money while still building a close-knit community with their followers. Encouraging goods and services that fit the influencer's beliefs and way of life promotes authenticity and keeps recommendations from being deceptive. Responsible messaging should always come first in content, especially when aimed at younger audiences. It is not appropriate to promote harmful behaviours or unattainable beauty standards. Influencers and corporations alike want to aim for natural content production that stays away from dramatic scenes or heavy editing.

5.3. Protecting Children

According to Sternreichisches et al. (2018), influencer marketing has many detrimental effects on children's consumption patterns as well as the formation of character traits and attitudes. It may encourage kids to buy certain brands and increase their materialistic tendencies, which might eventually cause financial hardship. Inappropriate content or inaccurate representations of body image can also have a detrimental effect on their growth. Parents may have frank conversations about sponsorships and promote critical thinking about internet material to shield kids from the pressure and inflated images of influencer marketing. Furthermore, laws mandating transparent disclosure and moral marketing from companies and platforms might guarantee a safer online environment where kids can learn media literacy and make wise decisions.

5.4. Collaborative Efforts

We need to take two steps to make the internet a safer place. In the first place, consumer awareness campaigns may educate everyone on the value of media literacy and enable parents to have frank conversations with their kids about sponsorships and prejudices. With greater openness from platforms and brands as a result of this informed audience's demands, sponsored content will be clearly labelled. Clear limits can also be established by industry rules. In particular, programming aimed at minors is shielded from deceptive practices by requiring explicit sponsorship notice. To protect kids from skewed images and overly commercial content, laws might also forbid the advertising of unhealthy or improper items and promote moral marketing techniques. Children can use the internet in a healthy environment if industry players and consumers collaborate.

5.5. Promoting Media Literacy

Media literacy makes you a shrewd social media navigator in the era of influencer marketing. You'll pick up skills to identify unseen sponsorships, sharpen your critical thinking to challenge spurious suggestions and identify sales-influencing strategies. This gives you the power to select your followers based on their morals, cut back on wasteful spending, and eventually take charge of your internet life. By putting in place educational initiatives in schools and communities, people—especially younger audiences—can acquire the critical thinking abilities needed to identify influencer bias, distinguish sponsored material, and behave ethically online. Promoting the use of reliable fact-checking sources can enable people to independently confirm the information provided by influencers and stop the spread of false information.

5.6. Addressing Mental Health Concerns

Encouragement of body positivity, particularly concerning mental health, may be a potent weapon in the fight against the detrimental effects of influencer marketing. Influencer marketing frequently presents highly Photoshopped images of beauty, which can cause problems with body image and poor self-esteem. Campaigns for body positivity combat this by endorsing a greater variety of body shapes and highlighting the value of individuality. Regardless of size or form, seeing realistic body portrayals can help people feel good about their bodies. This can greatly enhance mental health and lessen appearance-related worry. Influencer marketing may become more approachable and inclusive by featuring a variety of bodies and experiences. Everyone may enjoy a more favourable online environment as a result.

6. IMPLICATIONS OF THE STUDY

The study's exploration of an ethical influencer marketing environment reveals several advantages. Rebuilding customer trust through more openness might result in a more sincere relationship between influencers and companies. Prioritising child protection ensures that online spaces are safe for younger viewers, while an emphasis on authentic content development may improve the quality of campaigns. Effective rules and consumer awareness campaigns may be established by cooperative efforts between consumers, regulators, and

companies, promoting an ecosystem of responsible influencer marketing. Ultimately, media literacy enables customers to critically assess this environment and make well-informed judgements about what to buy. Influencer marketing may develop into a potent instrument based on ethics, safety, and trust by adopting these strategies, which will benefit both customers and companies. The significance of ethical principles for influencer marketing's sustained success is emphasised by this study. It's crucial to establish trust through openness and moral influencer alliances. Influencers should put more emphasis on authentic connections and transparent disclosure, while brands should prioritise authenticity and ethical metrics. By establishing precise rules and safeguarding susceptible audiences, regulators may contribute. Equipped with media literacy, consumers can demand openness and hold all parties involved responsible. Influencer marketing, when combined, has the potential to be a positive force in the digital space.

7. CONCLUSION

As a weapon in the modern marketer's toolbox, influencer marketing has two sides. Its efficacy depends on prudent procedures that minimise possible dangers, notwithstanding its enormous potential for audience engagement, brand growth, and sales acceleration. This essay has carefully considered all sides of the debate, analysing influencer marketing's effectiveness while also emphasising its necessity for careful application. In the current marketing landscape, influencer marketing has become a potent instrument. Through the utilisation of social media celebrities' reach and trust, companies may establish authentic relationships with their target audiences and cultivate a favourable brand image. This essay has looked at the many facets of influencer marketing and considered both its advantages and disadvantages.

In the always-changing digital world, influencer marketing has the power to positively affect brand perception, increase sales, and cultivate favourable brand associations. Influencer marketing may continue to be a potent force for good if we embrace ethical behaviour, encourage cooperation between stakeholders, and provide consumers with media literacy. Influencer marketing will eventually flourish in ethics and genuineness thanks to this cooperative strategy, which will benefit both customers and companies in the long run.

8. LIMITATIONS AND FUTURE SCOPE

Although there are several limitations, this study examined the possibilities of influencer marketing. The research prioritised theory over real-world applicability. Since influencer marketing is a dynamic industry, new ideas could come up that need more research. Notwithstanding these drawbacks, there are plenty of interesting topics for more study. It's critical to develop techniques for calculating influencer marketing programmes' return on investment (ROI). It's also critical to comprehend how influencer marketing affects customer behaviour and brand perception over the long run. More research should be done on the ethical ramifications, particularly concerning child protection and misleading advertising. Lastly, further research is necessary to determine how influencer marketing is impacted by artificial intelligence, virtual influencers, and new social media platforms. We can learn more about the role influencer marketing plays in the always-changing marketing landscape by resolving these constraints and following these prospective study opportunities.

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Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

Religious Tourism as a Catalyst for Sustainable Socio-Economic Development: Peace, Equity, and Security

Arshan Ali Khan[a]*, Harshit Gupta[b]

[a,b] *Department of Computer Science & Engineering, Rajshree Institute of Management & Technology, Bareilly (U.P.), INDIA*

*E-mail: arshanalikhan999@gmail.com

ABSTRACT

Religious tourism represents a transformative force in sustainable socio-economic development, functioning as both an economic catalyst and a bridge-builder between diverse communities. This multifaceted sector encompasses pilgrimage journeys, visits to sacred sites, and spiritual retreats that generate substantial economic benefits while fostering interfaith dialogue and cultural understanding. The sustainable development of religious tourism requires strategic integration of peace-building initiatives, equitable community participation, and comprehensive security frameworks to maximize its positive impact on local economies and social cohesion.

The economic potential of religious tourism is substantial, with approximately 300 million tourists visiting major religious sites annually and generating over 600 million national and international religious voyages worldwide. Research indicates that religious tourism can significantly impact local economies, with studies showing positive correlations of 0.77 on income generation, 0.66 on employment creation, and 0.72 on overall economic prosperity in traditional settlements. However, achieving sustainable religious tourism development requires addressing critical challenges including environmental impact, cultural sensitivity, and equitable benefit distribution. Successful implementation demands comprehensive frameworks that prioritize environmental stewardship, cultural preservation, and inclusive community participation while ensuring visitor safety and authentic spiritual experiences.

The synergy between religious tourism and sustainable development goals manifests through its capacity to promote decent work and economic growth, responsible consumption and production, and peaceful societies. Ultimately, religious tourism serves as a powerful instrument for achieving sustainable socio-economic development when implemented through collaborative governance structures that prioritize peace, equity, and security for all stakeholders.

Keywords: sustainability, socio-economic development, equity, peace-building

9. INTRODUCTION

Religious tourism emerges as one of the world's most transformative and rapidly expanding sectors, representing far more than spiritual journeying. This comprehensive exploration reveals how religious tourism functions as a multidimensional catalyst for sustainable socio-economic development while fostering peace, equity, and security across diverse global communities.

Religious tourism encompasses pilgrimage journeys, visits to sacred sites, spiritual retreats, and faith-based travel experiences that collectively generate substantial economic benefits while promoting intercultural understanding and social cohesion. The sector's significance extends beyond mere economic metrics, embodying profound capacity for bridge-building between diverse communities, fostering interfaith dialogue, and supporting comprehensive sustainable development frameworks.

10. THE GLOBAL RELIGIOUS TOURISM LANDSCAPE

10.1. Market Dynamics And Economic Scale

The global religious tourism market demonstrates remarkable growth trajectory and economic significance. Current market valuations indicate a sector worth $254.3 billion in 2023, projected to reach $671.93 billion by 2030 at a compound annual growth rate (CAGR) of 15.3%. Alternative projections suggest even more substantial growth, with estimates reaching $2.01 billion by 2031 and potentially $2.22 billion by 2032.

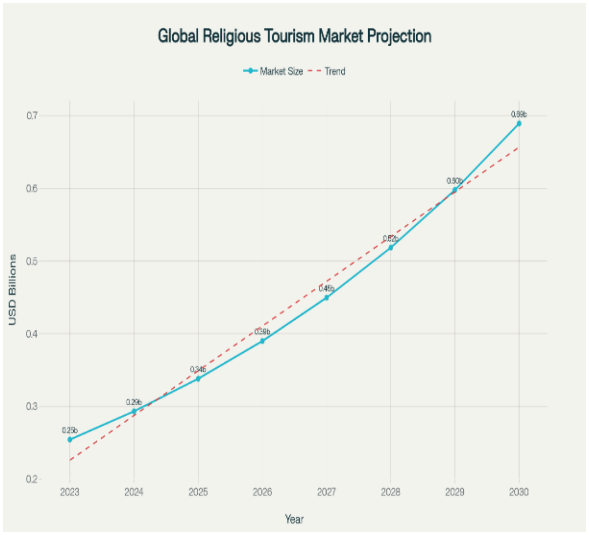

Figure.1.Global religious tourism market projected to grow from $254.3 billion (2023) to $689.3 billion (2030) at 15.3% CAGR

This exponential growth reflects increasing global interest in spiritual experiences, cultural heritage exploration, and meaningful travel. The sector's resilience, demonstrated through post-pandemic recovery, underscores its fundamental importance to both travellers and destination communities.

10.2. Major Religious Tourism Destinations

Religious tourism manifests through visits to sacred sites spanning all major world religions. Approximately 300 million tourists visit major religious sites annually, generating over 600

million national and international religious voyages worldwide. The most significant destinations include:

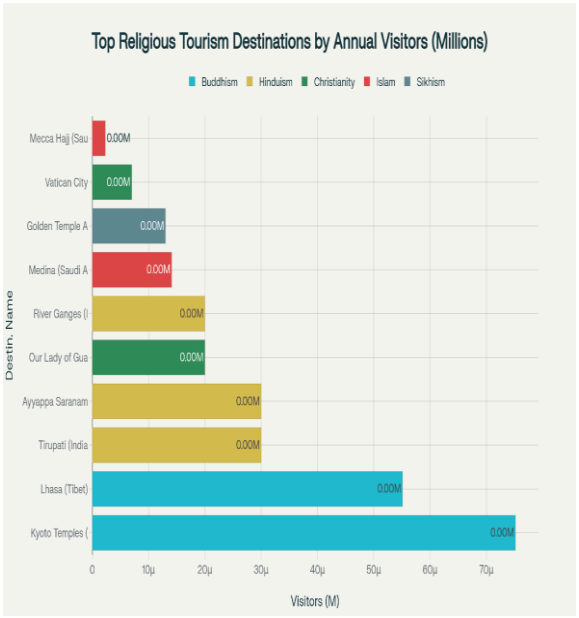

Figure.2.Kyoto leads religious tourism with 75.18 million annual visitors, followed by Lhasa and major Indian pilgrimage sites

The diversity of destinations reflects religious tourism's global reach, with Asia Pacific commanding significant market presence alongside Europe's dominant 30% market share, North America's 25%, and growing contributions from Middle East & Africa and Latin America

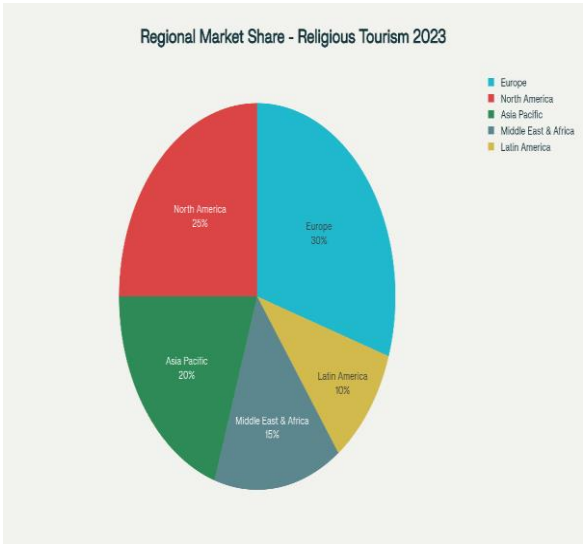

Figure.3.Europe dominates religious tourism with 30% market share, followed by North America (25%) and Asia Pacific (20%)

10.3. Regional Market Distribution

Regional analysis reveals Europe's leadership in religious tourism market share (30%), followed by North America (25%) and Asia Pacific (20%). This distribution reflects both established pilgrimage traditions and modern tourism infrastructure capabilities. The Middle East & Africa region, while currently representing 15% of global market share, demonstrates the highest expected growth rate at 16.5% CAGR, indicating substantial future potential.

11. RELIGIOUS TOURISM'S ECONOMIC IMPACT

11.1. Employment Creation And Local Economic Development

Religious tourism generates substantial employment opportunities across multiple sectors. Research indicates positive correlations of 0.77 on income generation, 0.66 on employment creation, and 0.72 on overall economic prosperity in traditional settlements. The sector creates employment in: Direct Services: Hospitality, transportation, tour guiding, food services, and religious artifact retail Indirect Benefits: Infrastructure development, construction, crafts production, and agricultural supply chains Induced Effects: Secondary spending by employees and service providers throughout local economies

11.2. Infrastructure Development Catalyst

Religious tourism serves as a powerful driver for comprehensive infrastructure development. Improvements typically include: Transportation Networks: Enhanced road connectivity, railway access, airport facilities, and last-mile transportation solutions. Public Utilities: Water supply systems, sewage treatment, electricity distribution, and telecommunications infrastructure. Healthcare and Safety: Medical facilities, emergency services, and security systems to accommodate large visitor volumes.

11.3. Revenue Generation Across Scales

The sector demonstrates remarkable revenue generation capacity across different scales: Global Scale: The sector contributes approximately 10% of world GDP and supports 1 in 10 jobs globally National Scale: India's religious tourism alone generated $16.2 billion in revenue in 2022, with projections reaching $59 billion by 2028. Local Scale: Individual sites generate substantial local revenue, with studies showing significant increases in occupancy rates and business revenues during religious festivals.

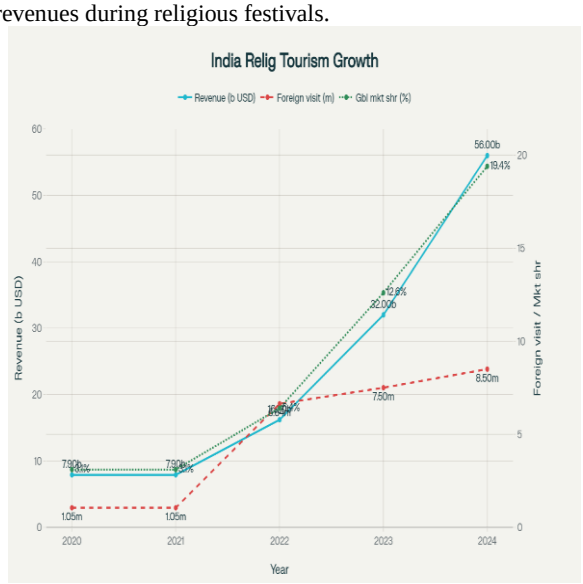

Figure.4.India shows remarkable religious tourism recovery: revenue grew from $7.9B to $56B, global market share from 3.1% to 19.4%

12. SUSTAINABLE DEVELOPMENT GOALS ALIGNMENT

12.1. SDG Integration Framework

Religious tourism demonstrates strong alignment with multiple Sustainable Development Goals, particularly:
SDG 8 (Decent Work and Economic Growth): Through employment creation, entrepreneurship opportunities, and economic diversification.
SDG 11 (Sustainable Cities and Communities): Via infrastructure development, cultural preservation, and community enhancement.
SDG 16 (Peace, Justice and Strong Institutions): Through interfaith dialogue, conflict resolution, and institutional strengthening.
Additional alignments include SDG 1 (No Poverty), SDG 10 (Reduced Inequalities), SDG 12 (Responsible Consumption and Production), and SDG 14 (Life below Water).

13. ENVIRONMENTAL SUSTAINABILITY CONSIDERATIONS

Religious tourism presents both challenges and opportunities for environmental sustainability. Research indicates that religious tourist arrivals and geopolitical stability can have mitigation effects on CO2 pollution levels, while transportation and foreign direct investment contribute more significantly to environmental degradation.

13.1. Sustainable Practices Include:

- Eco-friendly pilgrimage initiatives promoting public transportation and waste reduction
- Environmental education programs for tourists and local communities
- Natural resource conservation through responsible site management

14. PEACE-BUILDING AND INTERFAITH DIALOGUE

14.1. Historical Foundation And Contemporary Relevance

Religious tourism historically functions as a peace-building mechanism through cross-cultural exchange, diplomatic travel, and religious pilgrimages. Ancient trade routes like the Silk Road demonstrated early connections between religious travel and peaceful interaction.

Modern interfaith dialogue initiatives demonstrate religious tourism's capacity for promoting understanding across religious boundaries. The "Harmony Project" in Varanasi exemplifies contemporary efforts, bringing together spiritual leaders and community members from various religious backgrounds through shared events and community service projects.

14.2. Interfaith Collaboration Models

Successful interfaith collaboration in religious tourism contexts includes:
Morocco's Interfaith Development Model: Muslim-Jewish cooperation leading sustainable agricultural development, clean water infrastructure, and women's empowerment through community-managed fruit tree nurseries
Indian Interfaith Initiatives: Joint cultural festivals, dialogue workshops, and collaborative heritage preservation projects
European Integration Models: Multicultural education frameworks incorporating interfaith perspectives for sustainable development.

14.3. Conflict Resolution And Social Cohesion

Religious tourism contributes to conflict resolution through:

- Shared sacred space management requiring cooperation across religious boundaries
- Economic interdependence creating stakeholder incentives for peaceful coexistence
- Cultural exchange programs promoting mutual understanding and respect

15. COMMUNITY PARTICIPATION AND EQUITY

15.1. Participatory Development Models

Effective religious tourism development requires comprehensive community participation frameworks ensuring local stakeholders benefit equitably from tourism development. Key principles include: Inclusive Decision-Making: Community involvement in tourism planning, policy development, and resource allocation. Capacity Building: Training programs, education initiatives, and skill development for local populations. Cultural Preservation: Protecting traditional practices while accommodating tourism development.

15.2. Addressing Participation Barriers

Research identifies several barriers to effective community participation:

- Information Access: Limited knowledge about tourism opportunities and development processes
- Educational Constraints: Low literacy rates and technical skill gaps
- Resource Limitations: Insufficient financial capital for community-led initiatives
- External Dominance: Outside actors controlling tourism development without local input

15.3. Equity And Benefit Distribution

Ensuring equitable benefit distribution requires: Transparent Governance: Clear decision-making processes and accountability mechanisms. Community Ownership: Local control over tourism assets and revenue streams. Cultural Sensitivity: Respecting traditional practices and values in tourism development.

16. SECURITY FRAMEWORK AND RISK MANAGEMENT

16.1. Contemporary Security Challenges

Religious tourism faces diverse security challenges requiring comprehensive management frameworks:

Terrorism and Ideological Violence: Targeting of religious sites and pilgrims by extremist groups. Crowd Management: Safety concerns during mass gatherings and religious festivals. Natural Disasters: Environmental threats to heritage sites and visitor safety. Cultural Heritage Protection: Preventing looting, vandalism, and unauthorized alterations.

16.2. Risk Assessment And Mitigation Strategies

Effective religious tourism security requires: Comprehensive Risk Assessment: Evaluating threats to both physical safety and cultural integrity. Disaster Management Planning: Emergency response protocols for mass gatherings. International Cooperation: Collaborative security frameworks across borders. Technology Integration: Advanced monitoring and communication systems.

16.3. Protecting Cultural Heritage In Conflict Zones

Religious heritage faces particular vulnerabilities during armed conflicts, requiring: Emergency Documentation: Digital preservation of intangible cultural heritage. Community Empowerment: Supporting local guardianship of cultural assets. International Legal Frameworks: Strengthening protection under international law.

17. CASE STUDIES IN SUSTAINABLE RELIGIOUS TOURISM

17.1. India's Comprehensive Development Model

India represents a comprehensive model of religious tourism as sustainable development catalyst. The country hosts over 450,000 temples, mosques, gurudwaras, and churches managed by religious endowments and trusts. Key achievements include:

- 1,433 million domestic tourists visiting pilgrimage sites in 2022
- Revenue growth from $7.9 billion in 2021 to $16.2 billion in 2022
- Projected market value of $59 billion by 2028
- Expected creation of 140 million jobs by 2030

17.2. Regional Success Stories

Pakistan's Kartarpur Corridor: Demonstrates religious tourism's peace-building potential through visa-free access for Sikh pilgrims, generating revenue while promoting interfaith cooperation. Nepal's Boudhanath Stupa: Showcases sustainable community engagement in religious tourism development with positive cultural and economic impacts. Philippines' Religious Heritage Sites: Illustrate community-based approaches to religious tourism generating local economic benefits while preserving cultural traditions.

18. CHALLENGES AND CRITICAL CONSIDERATIONS

18.1. Environmental Impact Management

Religious tourism presents significant environmental challenges: Waste Generation: Large-scale religious festivals produce substantial waste requiring systematic management. Water Resource Strain: High visitor volumes stress local water supplies and sanitation systems. Ecosystem Disruption: Tourist activities impact fragile religious and natural heritage sites.

18.2. Cultural Commodification Risks

The commercialization of religious sites creates tensions between:

- Authentic spiritual experience and tourist market demands
- Traditional religious practices and modern tourism infrastructure
- Local community needs and external tourism investment

18.3. Governance And Institutional Challenges

Effective religious tourism governance requires addressing: Multi-stakeholder Coordination: Aligning interests of religious institutions, government agencies, private sector, and local communities. Regulatory Frameworks: Developing appropriate policies balancing development with preservation. Capacity Building: Training skilled professionals for heritage management and sustainable tourism.

19. FRAMEWORK FOR SUSTAINABLE RELIGIOUS TOURISM DEVELOPMENT

19.1. Integrated Development Approach

Sustainable religious tourism development requires comprehensive frameworks integrating:
Economic Sustainability: Revenue generation, employment creation, and economic diversification ensuring long-term viability. Environmental Stewardship: Resource conservation, waste management, and ecological protection. Social Equity: Community participation, cultural preservation, and equitable benefit distribution. Cultural Authenticity: Maintaining spiritual significance while accommodating tourism development.

19.2. Governance Structures

Effective governance frameworks should include: Participatory Planning: Community involvement in all development stages. Transparent Decision-Making: Clear processes for resource allocation and policy development. Accountability Mechanisms: Regular monitoring and evaluation systems. Conflict Resolution: Procedures for addressing disputes and competing interests.

19.3. Capacity Building And Education

Sustainable development requires: Professional Development: Training programs for heritage management, tourism services, and cultural interpretation. Community Education: Awareness programs about tourism opportunities, environmental

Figure.5.Global map of major religious tourism destinations by faith tradition

conservation, and cultural preservation. Visitor Education: Information campaigns promoting responsible tourism behavior

20. FUTURE DIRECTIONS AND RECOMMENDATIONS

20.1. Technology Integration

Religious tourism development should leverage technology for: Heritage Documentation: Digital preservation and interpretation of cultural assets. Visitor Management: Smart systems for crowd control and safety monitoring. Community Communication: Platforms facilitating stakeholder dialogue and collaboration

20.2. Policy Development

Governments should develop comprehensive policies addressing:
Integrated Planning: Coordination across tourism, heritage, environment, and development sectors. Investment Frameworks: Balanced approaches to public and private sector involvement. International Cooperation: Collaborative frameworks for cross-border religious tourism.

20.3. Research And Innovation

Future research should focus on: Impact Assessment: Long-term studies of religious tourism's social, economic, and environmental effects. Best Practice Documentation: Systematic analysis of successful sustainable religious tourism models. Innovation Development: New approaches to balancing development with preservation.

21. CONCLUSION

Religious tourism represents a powerful catalyst for sustainable socio-economic development when implemented through comprehensive frameworks prioritizing peace, equity, and security. The sector's capacity to generate substantial economic benefits—demonstrated through market projections exceeding $671 billion by 2030 and the creation of millions of jobs—positions it as a critical development tool for communities worldwide.

However, realizing this potential requires addressing significant challenges including environmental impact management, cultural preservation, and equitable community participation. Success demands collaborative governance structures integrating diverse stakeholders, sustainable practices protecting cultural and natural heritage, and inclusive approaches ensuring all community members benefit from tourism development.

The synergy between religious tourism and Sustainable Development Goals manifests through the sector's capacity to promote decent work and economic growth, responsible consumption and production, and peaceful societies. As destinations like India demonstrate remarkable growth trajectories and regions like Europe maintain market leadership while fostering interfaith dialogue, religious tourism emerges as an essential instrument for achieving the 2030 Agenda's ambitious goals.

Moving forward, the sector's transformation potential will depend on stakeholders' commitment to sustainable practices, community empowerment, and comprehensive approaches balancing spiritual authenticity with modern development needs. Through such integrated frameworks, religious tourism can continue serving as a bridge between cultures, a generator of prosperity, and a foundation for peaceful, equitable, and secure societies worldwide.

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Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

Artificial Intelligence Maturity Model: A Systematic Literature Review

Diyani Balthazaar[a*]

[a]*School of Business, Woxsen University, Hydrabad, Telangana 502345, India.*

*Email: diyanimathews22@gmail.com

ABSTRACT

Organizations in various industries have widely developed the artificial intelligence (AI) maturity model as a systematic approach. This study aims to review state-of-the- art studies related to AI maturity models systematically. It allows a deeper understanding of the methodological issues relevant to maturity models, especially in terms of the objectives, methods employed to develop and validate the models, and the scope and characteristics of maturity model development. Our analysis reveals that most works concentrate on developing maturity models with or without their empirical validation. It shows that the most significant proportion of models were designed for specific domains and purposes. Maturity model development typically uses a bottom-up design approach, and most of the models have a descriptive characteristic. Besides that, maturity grid and continuous representation with five levels are currently trending in maturity model development. Six out of 13 studies (46%) on AI maturity pertain to assess the technology aspect, even in specific domains. It confirms that organizations still require an improvement in their AI capability and in strengthening AI maturity. This review provides an essential contribution to the evolution of organizations using AI to explain the concepts, approaches, and elements of maturity models.

Keywords Artificial Intelligence, Maturity model, Systematic literature review, Organization

1. INTRODUCTION

Artificial intelligence (AI) is considered the lifeblood of an organization in different industries. It is a disruptive technology that changes the conventional manner of working in an organization sustainably and radically (Gentsch, 2018). Moreover, besides structured data, AI can deal with data uncertainty (i.e. incomplete data or inadequate documentation), making it widely used to solve engineering and industrial problems (Abdullah & Ahmad, 2015; Kiat, Malek & Shamsuddin, 2019). There are various technologies under AI, including machine learning, deep learning, natural language processing models, computer vision, and machine reasoning, which can produce this multimodal knowledge (Dahlan, 2018). Thus, AI could be defined as the ability of a system to correctly interpret external data, produce knowledge from those data to accomplish specific goals and tasks through resilient adaptation (Haenlein & Kaplan, 2019; Kurniawan et al. 2018).

In the Fourth Industrial Revolution (4IR) era, with exponentially increasing information assets in organizations (Bakar, Razali & Jambari, 2020; Hassan, Yusof & Ahmad, 2019) and the need for measurements and forecasting future values (Khaki et al., 2016), many organizations are investing in adopting AI to increase their capability. The importance of intelligence originates from its ability to add a competitive advantage to an organization over its rivals, create added value through enhance performance, productivity, effectiveness with low cost, increase the work of executives and staff, speed up the process, and cater better to customers (Gentsch, 2018; Lichtenthaler, 2020; Seger, Miailhe & Mueller, 2019; Zhang, Song & He, 2020). Despite these benefits of AI, some organizations are still far from applying AI to their businesses or their value chain (Lichtenthaler, 2020). Some have adopted AI technologies in their business but are still at an early stage, with limited benefits achieved (Mikalef, Fjørtoft & Torvatn, 2019; Nortje & Grobbelaar, 2020). For example, Lamberti et al. (2019) surveyed to reveal whether AI in the pharmaceutical industry is mature or not. The results revealed that the AI maturity overall was assessed at the nascent level by 75–100% of the highest rating respondents. Besides that, two out of five considered AI functions are immature due to the substantial unrealized potential focused on an integrated intelligence architecture for further improving their competitive positions (Lichtenthaler, 2020). In other words, the implementation of AI should be organization-wide; otherwise, it will achieve a fraction of the realizable value (Seger, Miailhe & Mueller, 2019).

Organizations face various challenges, such as implementation costs, insufficient volume of relevant data, and misalignment of strategic goals, whereby the prominent challenges are typically human-related issues (Burgess , 2018). Besides that, organizational implementation, specialization and expertise, AI safety (trust, privacy, and ethical concerns), no governance to direct the process, inertia (reluctance to change work practices), infrastructure, and lack of top management support are additional business challenges and concerns in the transformation process. The latter also revealed that the most significant challenges in implementing and adopting AI are safety and data, followed by specialization, expertise, and inertia (Kılınç & Ünal, 2019; Mikalef, Fjørtoft & Torvatn, 2019). All above indicate that organizations face a great challenge during the implementation and integration of AI into their businesses, and part of this includes the maturity and readiness of the business to apply AI (Saari, Kuusisto & Pirttikangas, 2019). Even organizations that are considered "AI leaders" and constantly improve AI capability and create more value still do not leverage their organization's full AI strategy space or not in large parts of their organizations (Lichtenthaler, 2020). Thus, the business that invests in AI implementation ensures long-period survival and improved performance, while the others will be eliminated in the near future (Lamberti et al., 2019).

To help organizations find a path to enhance their performance and meet their objectives by evaluating their capability, the notion of the "maturity model" was invented. Maturity models are action-oriented standards that consist of discrete maturity levels for a class of processes or organizations. It represents the stages of increased quantitative or qualitative capability changes of these processes or organizations to evaluate their progressions concerning defined focus areas (Becker, Knackstedt & Pöppelbuß, 2009; Dzazali & Zolait, 2012; Fraser, Moultrie & Gregory, 2002; Kohlegger, Maier & Thalmann, 2009). This helps users understand the requirements to change and take the appropriate steps to accompany the change process (Bahri & Fauzi, 2018; Felch, Asdecker & Sucky, 2019). Mohammad et al. (2009) emphasizes the importance of assessing their current business excellence maturity level as a critical factor in its model to choose the right initiatives that lead to increased efficiency, productivity, and

sustainability to achieve excellence. The Capability Maturity Model (CMM) was released in the early 1990s to evaluate Software Process maturity in organizations (Abd Hamid & Mansor, 2016; Paulk, 2009). It serves as a reference model for software process improvement (SPI) efforts in hundreds of software companies across the world (Herbsleb & Goldenson, 1996). Since then, plentiful maturity models were developed in various domains to assess competency (De Bruin et al., 2005). Maturity model research has been introduced in more than 20 fields, but software development and software engineering disciplines are still heavily dominated (Wendler, 2012). Table 1 summarizes some of the previous reviews related to different maturity models.

Table.1.Summary of published reviews on maturity models

Author	Approach	Scope	Characteristics
Ochoa-Urrego & Peña-Reyes (2021)	Three stages planning, conducting, and reporting, and dissemination) was proposed based on Tranfield, Denyer & Smart (2003) related to different layers of business architecture.	-16 articles -Scopus, EBSCO, ProQuest, and Web of Science -Six models and a model presented by the Ministry of ITC in Colombia.	The framework used for model design is the Multidimensional orientation. However, the biggest interest is oriented towards the strategy and business layers which cannot guarantee any transformation process.
Lasrado, Vatrapu & Andersen (2015)	Five main steps starting from identifying raw keywords search until to selecting the relevant papers in IS domain.	- 34 articles within 1999 to 2014 - IS conference proceedings, books in ACM, AIS electronic library, IEEE explore, Springer link, and Business source databases.	A few maturity models that included theory, causal approaches, or hypothesis testing, the bulk of maturity models are conceptual in nature. The analysis demonstrates empirical validations of the models are scarce
Santos-Neto & Costa (2019)	Ten main steps from PRISMA (Moher et al., 2015) are used in classification framework to analyze and structure the selected publications (Tarhan, Turetken & Reijers, 2016; Webster & Watson, 2002; Wendler, 2012) and investigate the maturity models in different enterprise segments	- 409 articles until 2017 - ScienceDirect, SpringerLink, Scopus, Web of Science and lecture - Related to development, validation, or application of maturity models.	The studies are more descriptive approaches than prescriptive ones, focusing on the bottom-up approach. The level of maturity in most development and application papers was defined according to a scoring system
Bertolini et al. (2019)	A combination of qualitative and quantitative was utilized to comprehend maturity model trends and topics in general and the specific subjects and characteristics of maturity models.	- 65 articles - 9 articles are related to maturity models obtained from Scopus.	The majority of the literature falls under the Manufacturing and Information Systems subject categories. Therefore current maturity levels are focusing on socio-cognitive factors than on objectively measuring technology and knowledge stack.
Tocto-Cano et al. (2020)	Four main steps from (Keele, 2007) are used from process of identifying research questions until the systematization to evaluate maturity in university education domains.	- 23 articles between 2007 and 2020 - Scopus, Web of Science, ScienceDirect, IEEE, ERIC, EBSCO Discovery, and Wiley.	Nine categories were organized the selected articles based on their purposes. However, maturity models used in universities move towards agility, automation through ontologies and the semantic web; lack of guideline of best practices
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(2019)	Reijers, 2016; Webster & Watson, 2002; Wendler, 2012) and investigate the maturity models in different enterprise segments	application of maturity models.	
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One of these areas for which maturity models have been developed is AI. AI domain maturity models are valuable tools used to define the degree of 'readiness' to take advantage of AI (Saari, Kuusisto & Pirttikangas, 2019) by improving organizational performance to evaluate and enhance AI-created capabilities (Alsheibani, Cheung & Messom, 2019). An AI maturity model (AIMM) is used to assess intra-organizational AI capabilities (Coates & Martin, 2019), to guide in the AI journey (Burgess , 2018), and as a comparison of AI capabilities within an organization or with progressive organizations (Alsheibani, Cheung & Messom, 2019; Saari, Kuusisto & Pirttikangas, 2019). Thus, the organization should systematically identify its needs and abilities to create a prioritized portfolio of initiatives for AI (Saari, Kuusisto & Pirttikangas, 2019). While doing so, managers should evaluate the impact, feasibility, objectives alignment (ambitious), and availability of technology (Burgess , 2018; Saari, Kuusisto & Pirttikangas, 2019). To assess AI maturity, all the underlying AI dimensions (e.g., data, AI culture, etc.) of specific or all areas (e.g., automation, marketing, etc.) in an organization should be evaluated to obtain a result in terms of the total level of AI capability (Mikalef, Fjørtoft & Torvatn, 2019). In addition, the maturity models should be developed based on the theoretical foundation because the conceptualization of maturity models may be affected by various theoretical perspectives (Lasrado, Vatrapu & Andersen, 2015). Various AIMM were developed with different dimensions to evaluate and increase firm-wide AI capability or in specific areas of the firm. The purpose of this study is to conduct a systematic literature review (SLR) to provide an overview of the state-of-the-art AIMM, identify gaps in the literature, and identify opportunities for future work.

2. SURVEY METHODOLOGY

This work implemented a SLR to retrieve all the relevant research that targets AI and maturity models. This is attributable to its rigorous approach to provide answers to specific questions or to test particular hypotheses (Greenhalgh & Peacock, 2005; Okoli, 2015).

Therefore, extensive literature reviews have been performed to provide a thorough understanding and critical evaluation of the maturity models relevant to AI, besides finding new paths for research through identifying gaps. An eight-step guideline by Okoli (2015) is performed to help researchers enhance systematic reviews in information science (Fig. 1). It covers (i) Purpose of the literature review; (ii) protocol and training; (iii) searching for literature; (iv) practical screen; (v) data extraction; (vi) quality appraisal; (vii) synthesis of studies and (viii) writing the review. These eight steps are applied in the subsequent sections for a study of the AIMM. "Survey Methodology" describes steps (i) until (v), followed by steps (vi) and (vii) in "Synthesis Studies". Step (viii) is addressed in "Discussion". Finally, "Conclusions" summarized the outcomes of this review.

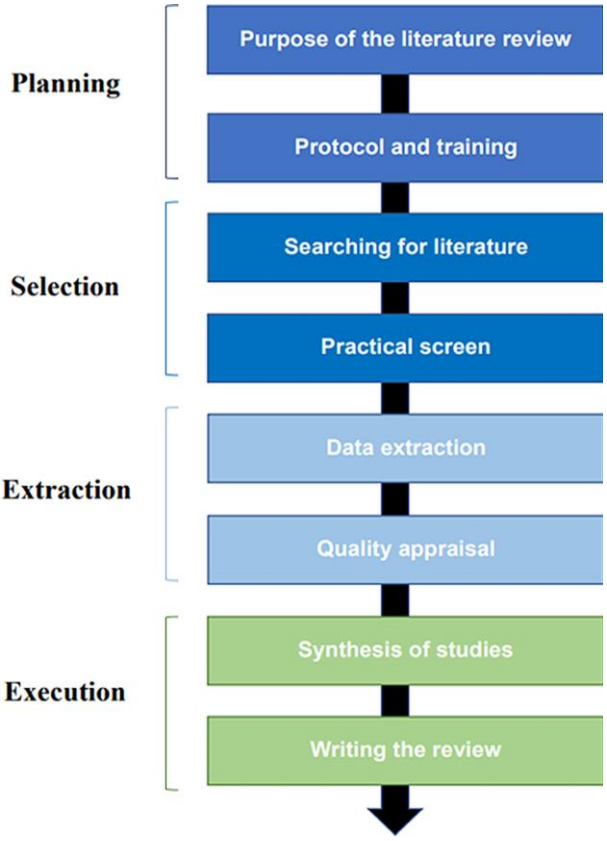

Figure 1 The methodology of the systematic literature review. Four phases of the systematic literature reviewcontaining eight main processes.

2.1. Purpose Of The Literature Review

The maturity model is used as a scale for assessing the position on the path of evolution (Becker, Knackstedt & Pöppelbuß, 2009). The position is identified by assessing the competency, capability, and level of sophistication of an organization in a

specific domain, based on a set of criteria that is more or less comprehensive (De Bruin et al., 2005). Each level or stage describes criteria and characteristics that need to be satisfied to achieve a specific level of maturity (Bahri & Fauzi, 2018; Becker, Knackstedt & Pöppelbuß, 2009). In addition, the description of the criteria and characteristics in the next level could be used as best-practices guidelines on how to reach a higher level (Fraser, Moultrie & Gregory, 2002).

Alsheibani, Cheung & Messom (2019) mentioned that the academic sources in this topic are scarce, and most of them are produced by analyst organizations, besides the theoretical background is missing. The same conclusion was reached by Ellefsen et al. (2019), who indicated that the AIMMs are established in a limited number of articles from Scopus or Web of Science databases. Various studies related to AIMM were conducted with different objectives. An evaluation is usually performed using a maturity model when organizations need to assess how far they are becoming an "AI-first" organization (Gemmink, 2019). A number of AIMM were developed to specify the degree of preparedness to benefit from AI in terms of improving organizational operations and processes, introducing new AI technologies, linking to the state of the company and its mindset, and estimating the performance of the organization enabled by AI technology (Saari, Kuusisto & Pirttikangas, 2019). Besides, these models must be tested for rigor and thoroughness to ensure their ability to be a well-rounded tool to reflect the current state of AI capability. This acted as a motivation for the following research questions:

RQ1: What are the main objectives in the literature on maturity models in the AI domain?
RQ2: What are the research methods used in the literature on maturity models in the AI domain?
RQ3: What is the scope of maturity models in the AI domain?
RQ4: Which design approach, typology, architecture, purpose of use, and components are used to design maturity models in the AI domain?

2.2. Protocol And Training

A strategic search strategy was used for analyzing and extracting relevant data. The protocol defined the criteria for inclusion, exclusion, keywords, the source databases, and quality assessment to ensure accuracy and consistency across the reviewers and papers. This step is necessary, regardless of the number of reviewers working on a study.

2.3. Searching For Literature

During the search process, eight academic digital sources were selected to extract relevant studies from the literature. Expert advice and prior systematic analysis were considered in this study to determine the database sources to be used. These databases cover the latest reliable literature topics and studies across all domains. The seven bibliographic databases considered are Scopus; Web of Science (WoS); Dimensions.ai; SpringerLink; ACM Digital Library; IEEE Xplore; and Pro-Quest. Another source, the academic search engine, Google Scholar has also been used since it is still the most comprehensive source (Martín-Martín et al., 2021). For the search string, the keywords used were "Artificial intelligence", "AI" and "maturity" to search for relevant papers. During the process, Boolean operators were utilized to gather literature that is as pertinent as possible. To narrow down and retrieve relevant results, "AND" and\or "OR" operators were used for databases and the search engine. In SpringerLink and Pro-Quest, the "NEAR" operator was used, which is equivalent to "AND".

Table.2.The databases and string searches used in this study

Sources	Search String
Scopus	("Artificial Intelligence" AND "Maturity")
WoS	("Artificial Intelligence" AND "Maturity")
Dimensions.ai	("Artificial Intelligence" AND "Maturity")
SpringerLink	("Artificial Intelligence" OR "AI") NEAR ("Maturity")
Google Scholar	("Artificial Intelligence Maturity" OR "AI Maturity" OR "Artificial Intelligence Process Maturity" OR "AI Process Maturity")
ACM Digital Library	Artificial Intelligence Process Maturity" OR "AI Process Maturity")
Pro-Quest	("Artificial Intelligence" OR "AI") NEAR ("Maturity")
IEEE Xplore	("Abstract": "Artificial Intelligence") AND "Abstract": "Maturity")

Note: Each of the sources containing different search strings to enhance the search outcomes.

The same approach is used to find articles where the keywords joined by the operator are within a certain number of words of each other. Since each search engine has its own way to work (e.g., search field and operators), each search string was changed to find the preferred results without reducing the validity of the research by missing relevant references. The changed search string was represented that previously defined in the SLR protocol. For this reason, in ACM Digital Library and IEEE Xplore, the searching process was conducted in abstracts (the most suitable choice) due to the limits of these search engines' choosing and the topic of research always be mentioned in the abstract. This study used the default number of words describing the allowed separation (10 in SpringerLink, 4 in Pro-Quest). Using this helpful operator in the two databases is due to the popularity of AI as a topic, and there are numerous studies related to it. In addition, "maturity" is a widespread word, and many studies use it as it is generalizable across many domains.

Besides that, the two latter databases contain books, theses, and dissertations that consist of mostly a hundred pages, which is costly in terms of time and effort. Therefore, by using "NEAR", only the relevant papers would be retrieved from the databases. On the other hand, besides "NEAR" and due to its functionality, the "OR" operator is included to ensure that we did not miss any important research that our mapping is seeking to address. In Google Scholar, the number of results was huge, and a high proportion of them was not relevant. Perhaps because it indexes the entire text of every article or recall papers that discussed only the main concepts in the full text (Martín-Martín et al., 2021). Thus, to minimize the results by retrieving only the relevant papers, the search string included "OR" operator. On the contrary, in the rest of the databases, the "OR" operator retrieved irrelevant sheets, which it became necessary to delete because the AI is short for other words like agile. All the academic literature was selected for the publication types, including journal articles, conference papers, book chapters, dissertations, and theses.

Therefore, to extract only the relevant materials, the search string was modified with the exact phrase. To define the state-of-the-art papers, only published papers after 2015 until September 2020 and written in English were selected. The databases and the search engine with their queries are listed in Table 2.

Table.4.Articles screening process from each databases.

Sources	Initially retrieved	Initially selected	Records screened I	Records screened II	Final selection
Scopus	241	241	26	10	5
WoS	57	17	4	2	0
Dimensions.ai	125	36	5	2	2
SpringerLink	119	108	24	4	3
Google Scholar	72	54	21	10	5
ACM Digital Library	8	0	0	0	0
Pro-Quest	43	33	3	1	0
IEEE Xplore	21	4	1	0	0
Total	686	493	84	29	15

Records screened II	Final selection
10	5
2	0
2	2
4	3
10	5
0	0
1	0
0	0
29	15

Note: The number of articles that were included in each step of the screening process from different databases.

2.4. The Screening I: Title

The metadata with the date of extraction was collected with their significance labeled. Initially, all the results of the databases and Google Scholar were reviewed for duplication resulting 493 papers selected from 686 for further investigation. The number of studies initially retrieved and selected in the databases and Google Scholar are shown in Table 3. In this review, the title of each paper was scanned and identified for possible relevance to this review. Any paper that does not refer to AI-related maturity was eliminated from further investigation. After the initial search and screening of the 493 specific studies, 84 important papers were found.

2.5. The Screening Ii: Abstract And Keywords

In the second screening process, the abstract and keywords of the publications were scanned for a deeper review and a better understanding of the papers that focus on maturity models-related AI. The inclusion criteria in this review are the studies that:

- refer to a maturity model that focuses on the AI domain (introduce, propose, develop, and validate).
- apply an AI maturity model to assess AI in an organization.
- publish as journals articles, conference papers, theses, dissertations, book chapters, and reports.
- are written in English and published after 2015.

On the other hand, the exclusion criteria used in this review are as the studies that:

- referring to a maturity model that focuses on a particular aspect of AI or a related field like machine learning, deep learning, or data maturity models.
- introduce or develop a method for assessing the AI capabilities' level of maturity in an organization, but do not refer to a generic model that meets the maturity model definition.
- mention AI maturity model or the keywords without enough information.
- refer to maturity models in domains other than AI.
- include experience papers, forums, comments, tutorials, opinions, or discussions.

To avoid losing potential contributions for the research topic, we decided to preserve all papers (not just peer-reviewed papers). A total of 29 studies met the inclusion criteria, as shown in Table 3. Another round of screening was applied to these articles examining their full text for quality appraisal of the elicited articles from the previous stage.

2.6. Quality Appraisal

The papers included in the second screening were fully read to determine their emphasis on AI relevant to maturity models and their importance to the research questions. These papers were analyzed accurately with a concentration on their aims, description, and methodology. A summary of information from the sample papers are filtered in the final screening stage on an excel sheet. Each part of this sheet contains details that would answer a specific research question. From this process, 14 articles were excluded, and a final sample of 15 primary papers conformed to all criteria were considered convenient for inclusion in this review.

2.7. Data Extraction

For AIMMs, prominent information was extracted, such as assessment models about procedures and methods used for these models, scope, and metrics. The final set of papers in this review show different attention to this information; some papers devote considerable effort, while others apply far less care to explain the details. A classification scheme was achieved to analyze and structure the final set of papers, as shown in Table 4. A set of classes and subclasses were identified for the classification scheme, based on contributions from the literature (Becker, Knackstedt & Pöppelbuß, 2009; De Bruin et al., 2005; Fraser, Moultrie & Gregory, 2002; Frick, Küttner & Schubert, 2013; Mettler, 2011; Wacker, 1998) and research questions. These classes aim to answer the defined research questions. The "N/A" label was used when there was insufficient information about a class in the study.

2.8. Synthesis Studies

In this section, all 15 papers identified from the literature were analyzed to obtain a deeper understanding of the topic and answer the research questions.

2.9. Sample Description

Three aspects of the main demographic statistical results from the papers are discussed, namely, sources, publication types,

and the year of publications, as shown in Figs. 2 and 3. The distribution over databases and Google Scholar discovers that Scopus held most of the publications on this topic. The literature search performed in this review started in 2016, showed that no paper on this topic was published in 2016 and 2017. The findings in this review is summarized in Figs. 2 and 3.

Table.4.Classification scheme of this review.

No	Class	Subclass	Description
1	Search Objectives	Development	Propose, adapt, or create a new maturity model in the AI domain
		Validation	Validate proposed or existing conceptual models
		Application	Deploy AI maturity models and assess the AI maturity of organizations.
2	Scope	AI domain	"General" or "Domain Specific" models for examining the maturity of AI
		AI analysis level	The AI level of analysis can be a company and/or department, project, system, and process
3	Research method	Analytical	Either conceptual, mathematical, or statistical methodologies
		Empirical	An experimental design like case studies, content analysis, or mixed methods
4	Design approach	Top-down	During the design process, the maturity levels were first established, and then the items of assessment.
		Bottom-up	The assessment item was first identified during the design phase and then the maturity levels.
5	Architecture	Stage	A cumulative set of activities included in each level have to be successfully accomplished before moving to the next level.
		Continuous	A collection of activities which can be separately approached. 6. Purpose of use
6	Purpose of use	Descriptive	It will provide a deeper understanding of the status quo of AI and establishes
		Prescriptive	It shows a roadmap for improvement, or it identifies the strategy and practices required to progress to the next maturity level.
		Comparative	It has mechanisms of comparison and is benchmarked with other domains.
7	Typology	Maturity grids	A matrix contains a number of maturity levels that attend to different stages of AI capabilities.
		Structured models	structure that is formal and complex, like the CMM
		Likert-like questionnaires	A series of questions in which the respondent identifies the level of AI maturity of the organization on a scale from 1 to n.
		Hybrid	Combination use of matrix grid and Likert-like questionnaires.
8	components	Description of level	If there is an explanation of the characteristics of each level, the value 'Yes' is used, or else 'No' is used.
		Elements	A set of practices /activities/capabilities that are used to analyse or evaluate the maturity level and lead to achieving a set of goals considered to reach higher levels of maturity.
		Descriptors	The distinguish name for each maturity level
		Names of maturity levels	Labels of levels
		No. of levels	The number of maturity levels as the degree of maturity

Note: The classification scheme of maturity models are describes according to their subclasses.

3. RESEARCH OBJECTIVES AND METHODS

The studies are classified into two categories, namely, analytical and empirical papers. Our analysis reveals that half of the studies approximately performed validation for the maturity models. There are seven conceptual studies wherein no testing or application of the existing models was performed. In terms of model validation, seven out of the 15 models were validated using various empirical research approaches. The validation phase is important to ensure the proposed model's comprehensiveness, consistency, and problem adequacy (Becker, Knackstedt & Pöppelbuß, 2009). Concerning the validation, only two article used a quantitative survey method, with more than 80 respondents based in Finland. The results show that many organizations have only just started exploiting

AI in their organizations. Only three papers out of seven implemented qualitative methods. Jaaksi, Koskinen & Jalava (2018) conducted interviews with 11 experts to validate the model. The highest proportion of validation approaches are mixed methods, such as in Coates & Martin (2019), who used a mixed research method by performing a quantitative survey followed by case studies which analyzed the results quantitatively and qualitatively. Ellefsen et al. (2019) combined survey instruments with multi-case studies that were conducted through interviews. Gentsch (2018) analyzed the content available on the internet of three organizations, with an extremely high level of automation. Regarding the development phase, the majority of the papers used qualitative methods (e.g., action research or case studies), but the dominant method is content analysis. The "Application" column is empty, which means no research has applied any existing AIMM.

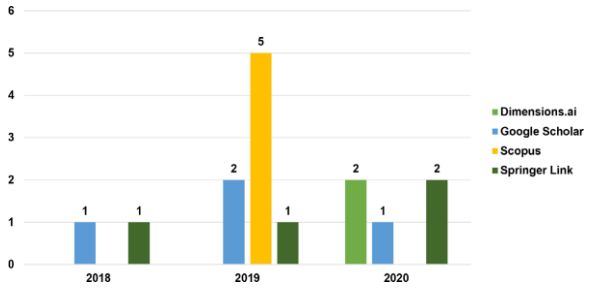

Figure 2 Distribution of articles per database and year. Each data indicates the total of publication published according to databases from 2018–2020.

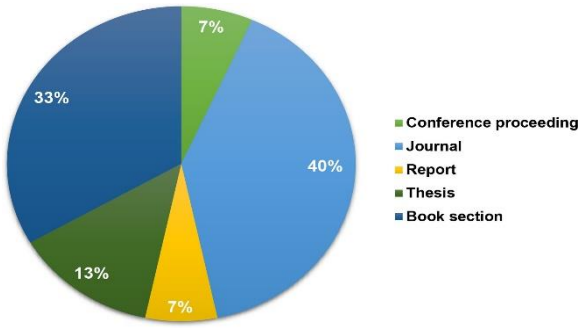

Figure 3 Distribution of articles by publication type. The percentage values (%) indicate the dis- tribution of all related articles per publication category.

3.1. Main Characteristics And Components Of Aimms

This section discusses the main characteristics and components of AIMM. Wendler (2012) indicated that not all the selected research had a clear definition of the term "maturity model" and this is also seen in our chosen studies. Only two studies out of 15 reviews contain different definitions of the term. The variation of the definitions proves that there is no consensus on a unified definition of the term 'maturity model'. The definitions of the maturity model in our findings studies are (i) an essential tool for describing existing production capabilities (Lee, 2020) and (ii) a measurement tool to evaluate the capabilities of an organization (De Bruin et al., 2005). Our findings were analyzed according to the classification in Table 4. According to the components, the elements in the maturity models under study have different designations, including "dimensions" (Lamberti et al., 2019), "constructs" (Mikalef, Fjørtoft & Torvatn, 2019), "elements" (Gemmink, 2019), "indicators" (Ellefsen et al., 2019), and "process areas" (Kumar, 2017). These findings reveal that these elements have different naming, and no standard terminology is available. This is in line with Poppelbub & Roglinger (2011), who reached the same conclusion. These elements are considered the heart of any maturity model, because their different capabilities represent the maturity levels. However, not all the selected models illustrated them clearly. Four or five levels are indicated in two models, without information about the dimensions used for evaluation. The authors define the principal components associated with each maturity model. The 15 research studies under review are explained briefly below in alphabetical order of the title. The information in all tables has the same order to simplify reading and comparison.

Study 1: Gentsch (2018) aimed to develop an AIMM for the marketing domain based on the AI business framework. Four levels of maturity, from the non-algorithmic enterprise to the automated enterprise, and finally super intelligence enterprise, the model showed the various stages of development regarding data, algorithms, and AI. Although the author included the "super intelligence enterprise" level as the highest maturity level, he indicated that it is difficult to reach this level at present. The model contained five dimensions: strategy, data, analytics, people/Orga, and decisions. However, there is no information about how these dimensions are evaluated to measure maturity.

Study 2: Kreutzer & Sirrenberg (2020) described an AI maturity map to determine the extent of existing AI and provide a path to start the AI journey in an organization. The analysis included two parts: AI basics and AI fields of application. Each part was evaluated separately by percentage value (a range from 0–20% to 80–100%). The four dimensions of AI basics should be evaluated for all organizations. Although the areas of application identified in this study were customer service, marketing/sales, service delivery, and production, it could decrease the current areas or include others like maintenance, human resources, and related fields based on the organization's focus. However, dimensions are not described at each level and there is no information about how these dimensions are evaluated to measure maturity.

Study 3: Saari, Kuusisto & Pirttikangas (2019) developed a free web tool to assess AI capability in a company context. The tool was developed by AI Accelerator (FAIA) in Finland, where the AI maturity index was first published in Finnish. This tool can be employed to evaluate the maturity in an organization to improve the understanding of the AI maturity level in different departments of the organization and possible areas of development, which is a valuable gauge before any development projects are launched. The model has six dimensions: strategy and management, products and services, competencies and cooperation, processes, data, and technology. The assessment method is carried out through questions, with five response alternatives to which each dimension has two questions. However, dimensions are not described at each level.

Study 4: Coates & Martin (2019) developed a new free self-assessment instrument reflecting the ethical values by actionable methods that would assess organization maturity to control AI bias efficiently. The instrument was designed to evaluate the project through two stages: Design and Development (during the project development) and Post-Development (after finishing the project's development). During the first stage, the evaluation can be performed multiple

times, with the expectation that companies can increase their maturity after each sprint. The constructs used in the design and development phase are business, people, user, data, algorithm, and compliance, and for the post-development phase are business, data, test, client feedback, and transparency. The maturity gain is a score as the sum of the relevant question' answers, divided by the maximum possible score, to give a proportion of performance independently. However, there is no evaluation of maturity levels after the scores to understand the level reached.

Study 5: Abele & D'Onofrio (2020) suggested an AI maturity to assess intelligence systems' intelligence capabilities. It provides a way to assess the level of technology growth in relation to one another or measure performance in a specific context. The model involves a two-dimensional classification where the x-axis represents the ability to deal with uncertainty, while the y-axis reflects the capability to solve problems adaptively. The adaptive method solves problems and shows the ability of a system to be applied in totally different contexts. The model shows that AI systems could be classified into five independent discrete categories. But there is no explanation on how to evaluate these systems.

Study 6: Tu, Lin & Lee (2019) proposed a metadata-driven automation maturity model for a clinical research company. The model intends to help these companies evaluate their processes' intelligent automation depending on their integration, efficiency, and intelligence. Three indicators were used to assess the maturity, which are: standard adoption (SA), code reusability (CR), and process repeatability (PR). All indicators' capabilities were described using nine maturity levels.

Study 7: Bangalore Seetharam (2020) presented a digital AI maturity ladder for retail organizations in different industries. The ladder was developed to enable them to know the current state of AI and offer a guideline to increase AI adoption against time, depending on the organization's ambition. The ladder consists of ten steps with four drops (stages), whereby each step defines the subsequent progression in becoming an AI-driven organization and gaining better value. Drop 2 is considered the start point to embark on AI. There are generic descriptions for drops with descriptors, but the capabilities used to evaluate the drops were not clarified. The author mentions that the evaluation was conducted through interviews.

Study 8: Lichtenthaler (2020) proposed a conceptual framework with three elements used to construct the five levels of maturity to manage AI in a company and helps to recognize the managerial challenges and significant resource limitations of organizations. The three elements are various types of AI, various types of human intelligence, and the meta-intelligence to guarantee that the final architecture is more than the aggregate of the different types of intelligence. This framework was built on the grasp of intelligence architecture based on the concept of Integrated Intelligence and the intelligence-based view of company performance.

Study 9: Jaaksi, Koskinen & Jalava (2018) introduced a model that assesses the current maturity level of AI adoption in organizations to address the requirements of AI transformation. The result indicated that the most important five dimensions were correlated with the AI maturity of the company. Feasible quality and quantity of the data to be used to implement the designed solution, workers who have the expertise and skills to create the designed solutions internally or successfully. The state of the organization with the current implemented solutions and the organization's mentality to adopt AI solutions. All capabilities of dimensions were indicated in four levels with detailed descriptions.

Study 10: Lee (2020) proposed a maturity capability assessment method of crucial technologies in Industrial AI. The objective is to create a thorough assessment of an enterprise's level of Industrial AI development to provide a foundation for its decision- maker and motivate to improve and address its deficiencies. By matching the four elements with the intelligent transformation stages, the level of industrial AI maturity would be determined. The assessment is based on four technologies, namely, Data (DT), Analytics (AT), Platform (PT), and Operation (OT) technologies. He explained each technology's capabilities separately in several maturity stages (all have four stages, except Analytics, which has five stages). However, the author did not explain the procedure to evaluate these capabilities.

Study 11: Yablonsky (2019) used a previous AI automation framework and AI/Big Data (BD)/Advanced Analytics (AA) value framework to produce a multi-dimensional data- driven AI enterprise innovation maturity framework to assist with strategic innovation planning and AI-based automation investment decisions. The framework concentrates on data-driven human-machine relationships and implementing AI at five levels of data- driven automation maturity scope, from activities and tasks to AI processes and platforms. The evaluation method to determine the level does not exist.

Study 12: Burgess (2018) suggested an AI maturity matrix and AI heat map to draw the path for an organization to initiation the AI journey, and offers an opportunity to identify the roles and opportunities of AI palpably and automation across the business which are acceptable and technically and economically feasible. Four criteria in the AI heat map (Strategic objectives, Existing challenges, Benefits, and AI capabilities) were used according to their processes in areas (customer service, organization, operations, and finance).

All six maturity levels, from level zero to level five were defined and each level comprises related practices for a predefined set of process areas that enhance the performance of an organization. The evaluation process could be determined through interviews and evidence analysis.

Study 13: Ellefsen et al. (2019) presented an AIMM framework to measure the AI readiness of logistics companies. The authors developed a survey instrument (questionnaire) to understand and evaluate the current situation of existing solutions of Logistics 4.0 and the implementation of AI in logistics companies. The four maturity levels of AI maturity for communication service providers (CSP), produced by Ovum, were used for AI levels evaluation. The results revealed that all the selected companies were still at a novice level.

Study 14: Seger, Miailhe & Mueller (2019) proposed an AI maturity framework for Intergovernmental Organizations (IGO). The framework focuses on executives use, contains five levels of maturity. However, no information about the dimensions or how to apply this framework for evaluation was provided.

Study 15: Alsheibani, Cheung & Messom (2019) introduced a conceptual model to evaluate the AIMM to helps an organization to have a vision to effectively develop and implement AI. the dimensions of the model are: AI functions, data structure, people, and organization, to measure maturity. All capabilities were indicated using five levels with a particular descriptor.

This review proves that maturity models in the AI domain were developed with different components. Table 5 reveals that the AIMM has different designs regarding the number of levels, descriptors, and elements. Various descriptors were identified from the 13 models under study, which differ from one model to another. The elements column discovers different designations and that there is no standard terminology. But the majority used "dimensions", which is mentioned in seven studies. Only three studies are without element identification.

3.2. The Main Scope Of The Aimms

This section involves answering the third research question: What are is the scope of maturity models in the AI domain? The SLR identified five AIMMs that were developed to be applicable in a generic manner. The other 10 models were created with a particular focus on a specific domain or purpose, as shown in Table 6. Five studies developed models for particular domains, while eight studies developed models for specific purposes. Two of 10 studies strived to evaluate the intelligent automation process. The first one was conducted by Tu, Lin & Lee (2019) to develop a model depending on the environment of clinical research to evaluate intelligent automation. Second, Burgess (2018) developed a model to evaluate automation maturity that focused on AI tools essentially, either at the company level or specific area.

On the other hand, the AI maturity ladder was developed by Bangalore Seetharam (2020) for retail organizations. Ellefsen et al. (2019) developed a framework for evaluating AI in logistic companies. Regarding specific purposes, Coates & Martin (2019) developed a tool to evaluate AI bias governance in an entire projector company, while Yablonsky (2019) developed a framework to evaluate AI innovations as examples. Furthermore, two models were developed to evaluate the intelligence in the systems. Abele & D'Onofrio (2020) introduced a model to assess the intelligence systems based on their intelligence capabilities, while Lee (2020) developed a model to evaluate the technical aspect (AI capabilities) and provide a basic judgment about an enterprise's intelligent transformation stage.

Table.5.The components of AI maturity models.

Author	No. of levels	Descriptor	Levels description	Names of maturity levels	Elements
Gentsch (2018)	4	Yes	Detailed description	non-algorithmic, Semi-automated, Automated, Super intelligence	5 dimensions (Strategy, Data, Analytics, People/ Orga, and Decisions)
Kreutzer & Sirrenberg (2020)	5	Yes	Very brief description	0–20%, 20–40%, 40–60%, 60–80%, 80–100%	2 parts (AI basics and AI fields of applications) subdivided in 8 dimensions (AI targets/ strategy, AI budget, AI employees, AI systems), and (Customer service, Marketing/Sales, Service delivery, and Production).
Saari, Kuusisto & Pirttikangas (2019)	5	Yes	No	Does not exist / Not relevant, Preliminary, Defined, Managed, Excellent	6 dimensions (Strategy and management, Products and services, Competences and cooperation, Processes, Data, and Technology)
Coates & Martin (2019)	N/A	No	No	N/A	11 constructs assessed though two stages: Design and development (Business, People, User, Data, lgorithm and Compliance, transparency and accountability), Post- development (Data, Testing, Client feedback and Transparency and accountability)
Abele & D'Onofrio (2020)	5	Yes	Detailed description	Smart information systems, Reactive machines, Artificial Narrow Intelligence, Artificial General Intelligence, Self-aware AI	2 dimensions (Uncertainty and Problem-solving capability)
Tu, Lin & Lee (2019)	9	Yes	Detailed description	ML1,ML2, ML3, ML4, ML5, ML6, ML7, ML8, ML9	3 indicators (Standard adoption, Code reusability, and Process repeatability)
Bangalore Seetharam (2020) *Lichtenthaler (2020)*	4 5	Yes Yes	Generic description Detailed description	Early Learning, Lay Foundation, Leverage, Accelerate Initial Intent, Independent Initiative, Interactive Implementation, Interdependent Innovation, Integrated Intelligence	3 elements (Types of AI, AI-human intelligence interdependencies, and Meta-intelligence)
Jaaksi, Koskinen & Jalava (2018)	4	Yes	Detailed description	Level 1, Level 2, Level 3, level 4	5 dimensions (Workforce, Data management, Process, Organization status, and Organizational mentality)
Lee (2020)	5	No	Detailed description	N/A	4 elements (Data maturity, Analytics maturity, Platform maturity, and Operation maturity)

Yablonsky (2019)	5	Yes	Detailed description	Human Led; Human Led, Machine Supported; Machine Led, Human Supported; Machine Led, Human Governed; Machine Controlled	4 dimensions (Who produce insight, Who decide and how, Who acts based on decision, AA)
Burgess (2018)	6	Yes	Detailed description	Manual Processing, Traditional IT-Enabled Automation, Isolated, Basic Automation Attempts, Tactical Deployment of Individual Automation Tools, Tactical Deployment of a Range of Automation Tools, End-to-End Strategic Automation	4 capabilities (Strategic objectives, Existing challenges, Benefits, and AI Capabilities) are subdivided in 6 process areas (Customer Service, Operations, Finance, ITSM, HR, and Risk Assessment)
Ellefsen et al. (2019)	4	Yes	Very brief description	Novice, Ready, Proficient, and Advanced	N/A

Note: All related articles are summarized according to their maturity levels and and elements

Table.6. The scope of AI maturity models.

AI analysis level	Author	AI domain
Company/department	*Saari, Kuusisto & Pirttikangas (2019)*	General
Company	*Gentsch (2018)*	General
	Kreutzer & Sirrenberg (2020)	General
	Jaaksi, Koskinen & Jalava (2018)	General
	Ellefsen et al. (2019)	Logistic companies
	Seger, Miailhe & Mueller (2019)	Intergovernmental organizations
	Alsheibani, Cheung & Messom (2019)	General
Project/Company	*Coates & Martin (2019)*	AI bias governance
System	*Abele & D'Onofrio (2020)*	Intelligence
Process	*Tu, Lin & Lee (2019)*	Intelligent automation in Drug research
	Bangalore Seetharam (2020)	AI implementation management in Retail organization
	Lichtenthaler (2020)	AI management
	Lee (2020)	Industrial intelligent transformation in manufacturers
	Yablonsky (2019)	AI innovation management
	Burgess (2018)	Automation

Note: The previous AI maturity models are grouped into five AI analysis level.

This review reveals four levels of analysis with a scope: a company, process, project, and system levels. One study involved analysis within the scope of the project level (Coates & Martin, 2019). Six studies (Bangalore Seetharam, 2020; Burgess , 2018; Lee, 2020; Lichtenthaler, 2020; Tu, Lin & Lee, 2019; Yablonsky, 2019) assisted organizations in assessing the single process at the process level, while only one study focused on the system level (Abele & D'Onofrio, 2020). For example, AI management (Lichtenthaler, 2020) assists an organization in achieving an integrated intelligence architecture. At the same time, a data-driven automation framework (Yablonsky, 2019) enables an organization to concentrate on the relationship between data and human-machine interactivity and the implementation of AI at different levels of data-driven automation maturity scopes. The SLR listed 10 maturity models with a company-level scope to evaluate AI maturity of the entire Company. The SLR provides evidence that most of the maturity models were developed to be applicable for a particular focus on a specific domain or purpose. Additionally, most maturity models had a scope at the company level, followed by the process level.

3.3. Design, Typology, And Architecture Of The Aimms

This section explores issues related to the models' designs to answer the last research question. Not all of the studies indicate the design approach of the maturity model. Just four studies followed the bottom-up approach. No studies used a top-down approach. According to the topology, three studies followed Likert-like questionnaires as part of a quantitative approach. At the same time, one study (Burgess , 2018) used a structure like CMM to evaluate automation. Most studies used the qualitative description assessment approach (five studies followed the matrix grid). The dominant form to represent maturity is continuous representation. Only two studies used stage representation.

The final issue discussed in this section involves the benefits and purposes of use. The benefits of using maturity models could be descriptive, prescriptive, or comparative (Becker, Knackstedt & Pöppelbuß, 2009; De Bruin et al., 2005; Mettler, 2011; Poppelbub & Roglinger, 2011). The descriptive approach is used to evaluate the current situation of a domain as it is. The prescriptive approach is used to give a roadmap or vision to improve the AI in an organization. Finally, the comparative approach provides a comparison within an organization among a series of organizations. Poppelbub & Roglinger (2011) identified multiple purposes for using the same model during their analysis. This review also identified multiple purposes of use for most of the models, based on the information mentioned in the studies. For example, Gentsch (2018) explained that the model could be used to evaluate the current status with regards to AI, algorithms, and big data (descriptive), as a guideline to the next maturity level (prescriptive), and compare similar practices between organizations to evaluate maturity in different sectors (comparative). Saari, Kuusisto & Pirttikangas (2019) indicated that the final graph would compare an organization, among organizations, and with a reference group if there are sufficient

respondents (comparative). In addition, it is used as a self-assessment tool (descriptive), and its result helps the organization identify the most critical areas for improvement (prescriptive). Alsheibani, Cheung & Messom (2019) indicated that AIMM could be used to assess current AI capability (descriptive), offer managers with insights to adopt AI solutions (prescriptive), and benchmark against other advanced organizations to develop their AI capabilities (comparative) gradually. Most AIMMs have a descriptive characteristic (13 articles), but there is a lower amount that use the prescriptive purpose.

Table.7.The approach design, topology, architecture, and assessment purpose of AI maturity models.

Purpose of use	Author	Design approach	Typology	Architecture
Descriptive,	*Gentsch (2018)*	Bottom-up	Maturity Grid	Continuous
Prescriptive, and	*Saari, Kuusisto & Pirttikangas (2019)*	N/A	Likert-like questionnaires	Continuous
Comparative	*Alsheibani, Cheung & Messom (2019)*	Bottom-up	Likert-like questionnaires	Continuous
Descriptive and Prescriptive	*Kreutzer & Sirrenberg (2020)*	N/A	N/A	Continuous
Prescriptive	*Bangalore Seetharam (2020*	Bottom-up	N/A	N/A
	Burgess (2018)	N/A	Structured models	Stage
	Coates & Martin (2019)	N/A	Likert-like questionnaires	Stage
	Abele & D'Onofrio (2020)	N/A	N/A	Continuous
	Tu, Lin & Lee (2019)	N/A	Matrix grid	Continuous
Descriptive	*Lichtenthaler (2020)*	Bottom-up	N/A	Continuous
	Jaaksi, Koskinen & Jalava (2018)	N/A	Matrix grid	Continuous
	Lee (2020)	N/A	Matrix grid	Continuous
	Yablonsky (2019)	N/A	Matrix grid	Continuous
	Ellefsen et al. (2019)	N/A	N/A	Continuous
	Seger, Miailhe & Mueller (2019)	N/A	N/A	N/A

Note: All previous AI maturity models are categorized into their purpose of uses based on their design approach, typology and architecture.

(only six studies). In contrast, comparative approaches are largely unmet (only three papers). All the previous information is shown in Table 7.

4. DISCUSSION

AI is an important technology that uses in different sectors. However, using it in these sectors remains at an early stage. The importance of AIMM is to evaluate the current AI situation and achieve higher quality in various companies. Therefore, this review is conducted to give knowledge about the recent publications on this topic. In the study, a final sample of 15 papers was included based on the methodologies proposed by Okoli (2015). The majority of the studies' research objectives of AIMM focused on maturity model development, followed by validations. This finding appears to reflect a pattern observed in various domain investigations of maturity models (Wendler, 2012). It is a reflection of community dissatisfaction with existing approaches. However, the theoretical reflections of the maturity concept are mostly missing. A theoretical foundation is necessary to establish a well-founded development for a suitable and ready-to-use maturity model for practice and useful for other researchers. This leads to conclude that this topic needs more examination, especially since the number of documents is relatively small relative to other publications on maturation models in other domains. Process theory and resource-based view are an example of theories that could be used in AI research.

Most studies are empirical studies that have been conducted to develop or validate maturity models. It seems that this result usual and dominates the maturity models literature (Wendler, 2012). For designing the model, qualitative content analysis prevailed. This is normal where qualitative approaches are more used than quantitative methods when developing maturity model constructs (Lasrado, Vatrapu & Andersen, 2015). Seven (47%) out of 15 studies validated the design model, indicating that many AIMMs lack validation of their structure and applicability. However, this finding may explain why we could not find a study about the applicability of AIMMs in the sources. Some authors introduce the instrument (i.e., survey) to classify organizations and make some conclusions. However, the measurement tool was not tested on a sample for accuracy.

Validation is the degree to which the model accurately depicts reality and considers a sequel to the design procedure (Becker, Knackstedt & Pöppelbuß, 2009). It is necessary to check the validity, reliability, and generalizability of both the model construction and the model instruments (De Bruin et al., 2005). Thus, the without validation models of AI in reality raises questions about ensuring their practical relevance and competence to identify maturity levels. On the other hand, a sufficient (empirical) validation of the model is also essential. The most validation method is mixed methods or qualitative methods.

The mixed-methods approach used either mixed two qualitative methods or mixed qualitative and quantitative methods (most used approaches). This is because a mixture of quantitative and qualitative methods can provide more generalized insights (Wendler, 2012). For instance, after conducting a survey to validate the instrument by Coates & Martin (2019), case studies were followed through interviews to support the development by confirming results. Besides, it leads to attaining deep, accurate, and more reliable results. However, using two qualitative methods conducted by Gentsch (2018) is also useful because data triangulation using mixed methods will improve the model's reliability and validity. In

different papers, qualitative methods (e.g., case study, grounded theory) seem recommendable due to their ability to provide a deep understanding of the research's object.

Identifying the scope is the most critical step during the design process (Mettler, 2011). Two criteria for the scoping of the model: the focus of the model, which will determine the specificity and extensibility of the model within a particular domain (Bertolini et al., 2019). The second is development stakeholders, which define the source of knowledge and the possible audience (Bertolini et al., 2019). The scope of the maturity model should be linked with the demands of stakeholders (e.g., practitioners, academics, non-profit organizations) (Mettler, 2011). The review reveals that only one study mentioned that the ladder was developed based on the feedback received from the stakeholders (Alsheibani, Cheung & Messom, 2019). According to the focus of the models, this study reveals that most models narrowed the scope of the models to be applicable in specific industries or to be used for particular purposes. However, most of them are at the process level. This is due to no one size of AIMM that suits all organizations in different sectors (Alsheibani, Cheung & Messom, 2019). Creating an AIMM for a specific industry provides an opportunity to collect all the dimensions in the context whereby the AIMM for generic could not cover all of them. This leads, for example, Lasrado, Vatrapu & Andersen (2015) developing the model because there is no standardized measurement norm for the field of Industrial Intelligence to assess intelligence capability in the AI processes. Although, the trends of studies were focused on the company level, and most of them developed for general purpose. This is due to AIMMs at the company level's goal to gain a comprehensive view of the company's strengths by aggregating multiple capability areas (e. g., people skills, top leadership, or organizational culture) and the company's goals relevant to decision-making (Lichtenthaler, 2020). While at the process level scope focuses on technology issues obstructs identifying other critical elements that contribute to higher levels of AI capability. As a result, the applicability scope of the models is varied, and there is a balance between models developed at company and process levels. We believe that using AIMMs across various organizations will be beneficial, particularly for benchmarking AI capabilities. Furthermore, more studies focus on evaluating the maturity of the AI workforce (e.g., AI team) are needed.

Regarding the maturity model design, the SLR shows that four models use a bottom-up method, while none use a top-down approach. AI is not a new technology and uses in various organizations. This can explain the popularity of the bottom-up approach in AIMM design, which is more appropriate than a top-down approach which is more suitable if the domain is naive with little evidence to reflect its maturity (De Bruin et al., 2005). The remaining eleven papers make it difficult to define a feature that would lead to classification into either approach due to a lack of information when documenting the maturity model growth method. This finding indicates that the design approach that followed was not familiar in the maturity model.

When applying a maturity model, there are differences in the representation of the maturity level (stage or continuous) and the assessment method (matrix grid or Likert-like questionnaires). No papers identified using a hybrid of them, while only one study used a structure like CMM. This is because a hybrid or structure like CMM will increase the complexity of the model compared to the other Likert-type and maturity grids (Fraser, Moultrie & Gregory, 2002). This makes the process of determining maturity level does not present great difficulties. Six studies did not identify the topology of their models. It is obvious that continuous representation was used higher in the selected studies. The justification is presentation allows organizations to enhance their capabilities in particular process areas without allocating an area to a specific level of maturity (Fraser, Moultrie & Gregory, 2002). As a result, there is liberty in this representation to determine the sequence of improvement for the considered regions and processes.

According to the purposes of AIMMs, descriptive (13 articles) and comparative (three articles) approaches were found in 87% and 20% of the articles, respectively. These approaches have nature only identify problems or determine the status quo of capabilities, but neither of them indicates how to solve problems or increase the maturity level.

On the other hand, only 40% reflect a prescriptive method. The low number of papers with a prescriptive approach inhibits the practical implementation, and widespread use of these models, especially AIMM attempts to give guidance or a clear roadmap for achieving a greater level of maturity. Besides, the limited references to comparative studies demonstrate the emerging nature of this field and the necessity for development.

Every maturity model consists of several maturity levels that differ from model to model (De Bruin et al., 2005). It could be somewhat arbitrary, and the higher the number of levels, the more difficult and complex it is (Fraser, Moultrie & Gregory, 2002). Every level should include a label or descriptor with descriptions to clarify the characteristics of each level as a whole (De Bruin et al., 2005; Fraser, Moultrie & Gregory, 2002). This review exposes that there is differentiation in the number of maturity levels. The most frequent number is five levels, which is suitable because it would prevent the dispersion of details and make the development process less complicated. The number of maturity model elements varies as well, from one to another. These elements represent the domain components that are needed to evaluate maturity. The number of domain components and subcomponents, and specific capability areas within the domain components, should be kept low when designing a model to reduce the perceived complexity of the model and ensure the components' independence (De Bruin et al., 2005). This review reveals that Coates & Martin (2019) make up the most significant number of elements. This is because they developed an instrument to evaluate the AI bias governance in a project through two stages: Design and Development and Post Development.

The critical success factors identified from 13 studies are Data, Analytics, Technology and Tools, Intelligent Automation, Governance, People, and Organization, which could be considered the most critical dimensions. The elements were classified according to the explanations. Most elements in the ten studies are about evaluating intelligent automation and the intelligent levels of their systems. Only two studies concern governance, and one of them focus only on data compliance. Even the studies that developed maturity models to evaluate AI in the whole company did not pay attention to measuring it. The same conclusion to analytics is an essential dimension for developing a maturity model for the AI domain. The maturity model that does not capture all the relevant dimensions in its structure will not reflect the current AI capability situation. Furthermore, six out of 13 studies (46%) on AI maturity pertain to assess the technology aspect, even in specific domains. It confirms that organizations still require an improvement in their AI capability and in strengthening AI maturity.

The above indicates that the maturity models under review do not provide a complete image to evaluate and increase AI in companies. This finding is in line with Poppelbub & Roglinger

(2011), who mentioned that new maturity models are frequently introduced in scholarly papers as a rough theoretical sketch that is not appropriate for practical use. Scholars often fall short in offering comprehensive guidance and helpful (software-based or online) toolkits to promote the practical implementation of models established in academia.

Both the research and practitioner communities may benefit from the answers to these issues. Researchers can utilize the study results as a basic and inspiration for their own future research efforts. Simultaneously, the research could serve as a useful beginning point for practitioners. They can choose which AIMMs are suited for their work or determine which maturity notion is significant for them to deliver practical results.

5. CONCLUSIONS

AI is a vital technology that is used in a variety of organizations. However, its application is still at the early stages. Thus, adopting maturity models to assess the current state of AI and encourage adoption in diverse enterprises is critical. This paper examines various AIMMs used in academic studies to understand better the aims, research methods, and main characteristics of maturity models. Most of the papers' objectives are on the maturity model development (RQ1). Seven (47%) out of 15 studies have rigorously validated, focusing on mixed methods and qualitative methods. (RQ2). Out of 15 studies, 10 (67%) are designed for specific domains and purposes, while 12 studies (80%) their scope's levels are company and process (RQ3). The trend of models' design is a bottom-up design approach, maturity grid, and continuous representation with five levels and focus on descriptive purposes in the papers. The critical success factors identified from 13 studies are Data, Analytics, Technology and Tools, Intelligent Automation, Governance, People, and Organization, which could be considered the most critical dimensions for an organization. These results provide an answer to the last research question (RQ4).

No studies have paid attention to measure all the critical dimensions, even models designed on the company level. The model that does not capture all the critical dimensions will not reflect the current AI capability situation. Furthermore, a minimal number of works simultaneously study maturity models and AI, illustrating the need further to explore this research field with a theoretical background and collect all the critical dimensions to ensure that the organization or process situation is faithfully assessed. This research has some limitations. More research is required, either in other libraries or by using different keywords like (assessment maturity and AI or maturity matrix and AI) to identify more relevant papers.

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Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

Smart Cities and ICT for Sustainable Infrastructure: A Pathway to Inclusive Socio-Economic Development

Arshan Ali Khan[a]*, Harshit Gupta[b]

[a,b] *Department of Computer Science & Engineering, Rajshree Institute of Management & Technology, Bareilly (U.P.), INDIA*

*E-mail: arshanalikhan123@gmail.com

ABSTRACT

The rapid urbanization and escalating global challenges of climate change, resource scarcity, and social inequality demand innovative solutions that leverage technology for sustainable urban development. This research explores the transformative role of Information and Communication Technology (ICT) in building smart cities that prioritize sustainable infrastructure while fostering inclusive socio-economic development. Smart cities represent a paradigm shift in urban management, integrating ICT infrastructure with urban systems to create intelligent, responsive environments that enhance quality of life, promote sustainability, and drive economic growth. The convergence of technologies including Internet of Things (IoT), artificial intelligence, big data analytics, and 5G networks enables real-time monitoring and optimization of urban services from transportation and energy management to healthcare and governance. This research contributes to the understanding of how ICT-enabled smart cities can serve as catalysts for sustainable socio-economic development, providing frameworks for policymakers and urban planners to implement inclusive digital transformation strategies.

Keywords: ICT, Smart cities, sustainability

1. INTRODUCTION

The 21st century has witnessed an unprecedented wave of urbanization, with the United Nations projecting that nearly 70% of the global population will reside in cities by 2050. This rapid urban growth presents both opportunities and challenges, demanding innovative approaches to infrastructure development, resource management, and social inclusion. Smart cities have emerged as a transformative paradigm that leverages Information and Communication Technology (ICT) to address these urban challenges while promoting sustainable development and inclusive socio-economic growth.

Figure.1.key components of a sustainable smart city ecosystem, including smart homes, government, healthcare, transport, water, agriculture, waste management, renewable energy, and connectivity

The Smart City ICT Infrastructure market represents one of the fastest-growing technology sectors globally, projected to reach $42.01 million in 2025 and expand at a Compound Annual Growth Rate (CAGR) of 35.55% through 2033. This exponential growth reflects the urgent need for cities to adopt intelligent solutions that can optimize resource utilization, improve service delivery, and enhance quality of life for urban residents.

Smart cities integrate multiple technological layers, from IoT sensors and 5G networks to artificial intelligence and big data analytics, creating interconnected urban ecosystems that respond dynamically to citizen needs and environmental conditions. These systems enable predictive maintenance of infrastructure, real-time optimization of energy consumption, intelligent traffic management, and data-driven decision-making across all aspects of urban governance.

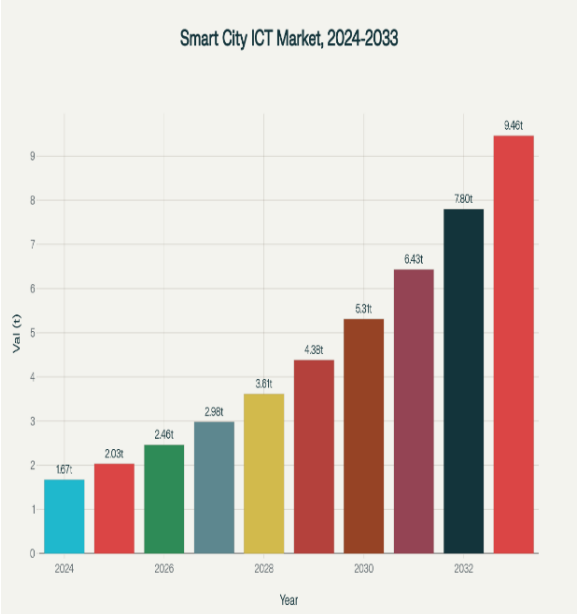

Figure.2.Global Smart City ICT Infrastructure Market Growth Projection (2024-2033)

The concept of sustainable infrastructure within smart cities extends beyond technological implementation to encompass environmental sustainability, social inclusion, and economic viability. Green building technologies, renewable energy integration, and circular economy principles are fundamental components that ensure smart cities contribute to global climate goals while fostering equitable development.

2. LITERATURE REVIEW

2.1. Evolution Of Smart Cities And Ict Infrastructure

The evolution of smart cities has been driven by the convergence of multiple technological advancements and urban challenges. According to IBM's definition, smart cities are urban areas "where technology and data collection help improve quality of life as well as the sustainability and efficiency of city operations". This definition underscores the dual focus on technological advancement and human-cantered development.

Historical development of smart city initiatives can be traced back to the 1960s when Los Angeles city leaders used data and computer programs to identify underfunded neighbourhood's requiring infrastructure investment. However, the modern smart city movement gained momentum in the 2000s with the proliferation of IoT devices, improved connectivity, and advances in data analytics.

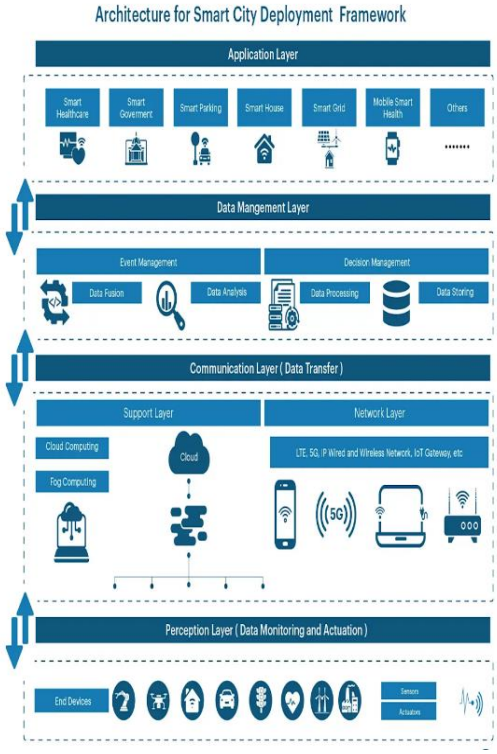

Figure.3.Architecture for smart city deployment illustrating IoT-enabled layers from perception sensors to application services via data management and communication technologies

Contemporary smart cities are characterized by multi-layered ICT architectures that integrate perception, communication, data management, and application layers. The perception layer comprises various sensors and IoT devices that collect real-time data from urban environments. The communication layer facilitates data transmission through technologies like 5G, fiber optics, and wireless networks. The data management layer processes and analyzes collected information, while the application layer delivers services to citizens and city administrators.

2.2. Iot Applications In Smart Cities

The Internet of Things has emerged as a critical enabler of smart city functionality, providing the sensory infrastructure necessary for real-time monitoring and responsive urban management. IoT-enabled sensors facilitate data collection across multiple urban domains, including air quality monitoring, transportation optimization, disaster management, and resource efficiency. Research indicates that IoT applications in smart cities span diverse sectors, with transportation accounting for 25% of implementations, followed by energy management at 20% and healthcare at 18%. These applications demonstrate measurable impacts on urban sustainability, with cities like London implementing 100 IoT sensors for air quality monitoring and Singapore utilizing IoT technology for integrated waste management that improves treatment efficiency while reducing greenhouse gas emissions.

3. 5G Networks And Urban Connectivity

The deployment of 5G networks represents a significant advancement in smart city infrastructure, enabling ultra-fast connectivity, low latency communication, and massive device connectivity. 5G technology supports up to one million device connections per square kilometer through massive Machine Type Communication (mMTC), facilitating high-density IoT deployments essential for comprehensive urban monitoring.

Figure.4.Visualization of 5G network connectivity enhancing smart city infrastructure through digital data flows and IoT integration in an urban environment

The transition from 4G to 5G networks offers dramatic performance improvements, with 5G providing 954% faster download speeds and 311% faster upload speeds compared to 4G. This enhanced connectivity enables real-time applications including autonomous vehicles, intelligent traffic management, and emergency response systems that require minimal latency for effective operation.

Gartner predicts that by 2024, 60% of communication service providers will commercialize 5G services covering Tier-1 cities, accelerating the transformation from smart cities to cognitive cities. These cognitive cities utilize 5G-enabled artificial intelligence and machine learning to enhance urban service performance and enable predictive, proactive city management.

3.1. Artificial Intelligence And Predictive Analytics

Artificial intelligence and predictive analytics constitute the cognitive layer of smart cities, transforming raw data into actionable insights for urban management. AI-powered systems analyse vast datasets from IoT sensors, satellite

imagery, and social media feeds to optimize resource allocation, predict infrastructure maintenance needs, and enhance public safety. Predictive analytics applications in smart cities include traffic congestion forecasting, energy consumption optimization, crime prevention, and epidemic control. Cities implementing AI-driven traffic management systems have achieved 15-20% reductions in congestion and 30% improvements in traffic law compliance. Similarly, predictive maintenance systems enable proactive infrastructure management, reducing operational costs by 10-15% while improving service reliability.

4. METHODOLOGY

This research employs a comprehensive literature review methodology, analysing 73 peer-reviewed publications and industry reports published between 2019 and 2025. The systematic review focused on identifying current trends, technological innovations, implementation challenges, and economic impacts of ICT-enabled smart city initiatives. Data sources included academic databases, government reports, industry analyses, and case studies from leading smart city implementations worldwide. The review prioritized recent publications to capture the latest technological developments and implementation experiences, with particular attention to COVID-19's impact on digital transformation and urban technology adoption.

The analysis framework categorized findings into five key domains: technological infrastructure, sustainable development applications, economic impacts, implementation challenges, and digital inclusion considerations. This multi-dimensional approach ensures comprehensive coverage of smart city ICT infrastructure's role in sustainable urban development.

5. SMART CITY ICT INFRASTRUCTURE COMPONENTS

5.1. Core Technology Stack

Modern smart cities rely on a sophisticated technology stack that integrates multiple ICT components to create responsive, intelligent urban environments. The foundational layer comprises connectivity infrastructure, including fiber optic networks, 5G cellular systems, and wireless technologies that provide the communication backbone for all smart city applications.

IoT devices and sensors form the data collection layer, deployed across urban infrastructure to monitor environmental conditions, traffic patterns, energy consumption, and service utilization. These sensors range from simple temperature and humidity monitors to sophisticated air quality analysers and intelligent traffic management systems. Cloud computing and edge computing platforms provide the computational infrastructure necessary for processing vast amounts of urban data. Edge computing reduces latency by processing data closer to its source, enabling real-time decision-making for critical applications like traffic management and emergency response.

5.2. Data Management And Analytics

Smart cities generate massive volumes of data that require sophisticated management and analysis systems. Big data

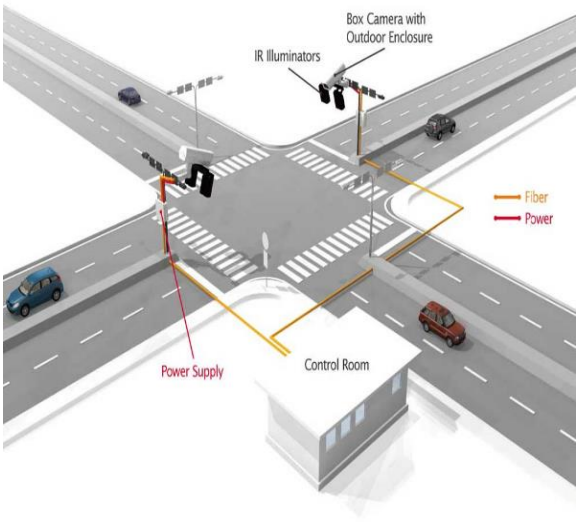

Figure.5.Schematic of an IoT-based smart traffic management system showing cameras, IR illuminators, fibre and power connections to a control room at an intersection

Analytics platforms process structured and unstructured data from multiple sources, including IoT sensors, mobile devices, social media, and government databases.

Machine learning algorithms and artificial intelligence systems analyze this data to identify patterns, predict trends, and optimize urban services. These systems enable predictive maintenance of infrastructure, energy demand forecasting, and dynamic resource allocation based on real-time conditions. Data governance frameworks ensure privacy protection, security, and ethical use of citizen data while enabling innovation and service improvement. Cities must balance transparency and open data initiatives with privacy protection and cyber security requirements.

5.3. Application Layer Services

The application layer delivers smart city services directly to citizens, businesses, and government agencies. These applications span multiple domains including smart transportation, energy management, healthcare, education, and governance services. Mobile applications and digital platforms provide citizens with access to city services, real-time information, and participation opportunities in urban governance. These platforms enhance transparency, improve service accessibility, and enable citizen engagement in decision-making processes.

6. SUSTAINABLE INFRASTRUCTURE DEVELOPMENT

6.1. Green Building Integration

Smart cities prioritize sustainable building practices that integrate advanced technologies with environmental responsibility. Green buildings in smart cities incorporate energy-efficient systems, renewable energy sources, and intelligent building management systems that optimize resource consumption.

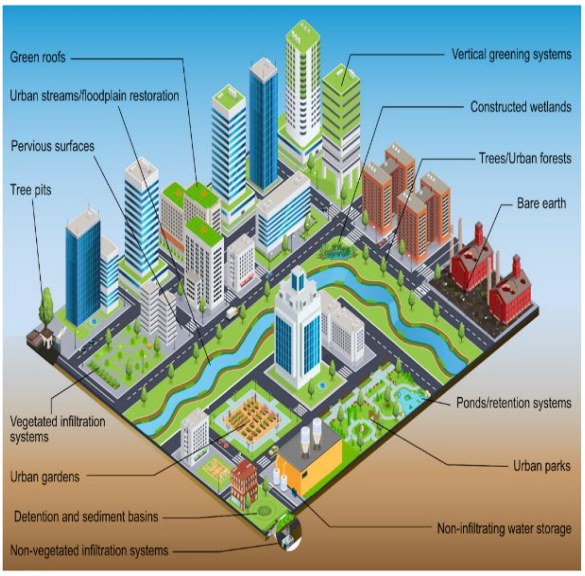

Figure.6.Illustration of urban green infrastructure elements integrated into a sustainable cityscape, including green roofs, urban forests, constructed wetlands, and water management systems

IoT-enabled building automation systems monitor and control heating, ventilation, air conditioning, and lighting systems to maximize energy efficiency while maintaining occupant comfort. These systems can reduce building energy consumption by 20-30% through predictive maintenance, occupancy-based control, and integration with smart energy grids. Smart buildings also incorporate water conservation technologies, including rainwater harvesting, greywater recycling, and smart irrigation systems that optimize water usage based on weather conditions and soil moisture levels. These technologies contribute to urban water security while reducing infrastructure stress during peak demand periods.

6.2. Renewable Energy Integration

Smart energy grids represent a critical component of sustainable smart city infrastructure, enabling the integration of renewable energy sources while maintaining grid stability and reliability. IoT sensors monitor energy production from solar panels, wind turbines, and other renewable sources, automatically adjusting distribution based on demand and availability.

Energy storage systems, including battery technologies and pumped hydro storage, provide grid stability during periods of variable renewable energy production. Smart grid technologies enable bidirectional energy flow, allowing buildings and electric vehicles to contribute excess energy back to the grid during peak demand periods.

District energy systems and microgrids enhance energy resilience while reducing transmission losses associated with centralized power generation. These localized energy networks can operate independently during emergencies while contributing to overall grid stability during normal operations.

6.3. Circular Economy Implementation

Smart cities implement circular economy principles through intelligent waste management, resource recovery, and industrial symbiosis facilitated by ICT systems. IoT sensors in waste containers monitor fill levels and optimize collection routes, reducing fuel consumption and operational costs by 10-15%. Waste-to-energy facilities convert municipal solid waste into electricity and heating, contributing to urban energy security while reducing landfill requirements. Smart sorting systems utilize AI and robotics to improve recycling efficiency and material recovery rates.

Water recycling and treatment systems integrate IoT monitoring to ensure water quality while maximizing reuse opportunities for irrigation, industrial processes, and non-potable applications. These systems reduce freshwater demand while minimizing wastewater discharge.

7. ECONOMIC BENEFITS AND COST ANALYSIS

7.1. Market Growth And Investment Trends

The global Smart City ICT Infrastructure market demonstrates remarkable growth trajectory, valued at $1,664.68 billion in 2024 and projected to reach $5,178.23 billion by 2033. This exponential growth reflects increasing government investments, private sector engagement, and citizen demand for improved urban services.

Economic development impacts of smart city technologies extend beyond direct infrastructure investments, with ABI Research estimating over $20 trillion in additional economic benefits through 2026. These benefits manifest through productivity improvements, cost savings, innovation ecosystem development, and enhanced business environments.

Open data policies alone can generate close to $1 trillion in incremental GDP growth without requiring physical infrastructure investments. Public investments in smart city technologies demonstrate multiplier effects of up to 10 times, potentially generating $10 trillion in incremental GDP growth.

7.2. Sector-Specific Economic Impacts

Transportation represents the largest economic opportunity within smart city implementations, with potential benefits of $2.8 trillion globally. Intelligent transportation systems reduce congestion, improve logistics efficiency, and enable new mobility services that enhance economic productivity. Energy sector applications generate approximately $1.6 trillion in economic benefits through improved grid efficiency, reduced energy waste, and integration of renewable energy sources. Smart energy management systems reduce operational costs while enabling new energy service business models.

Healthcare applications contribute $1.4 trillion in economic value through telemedicine, remote monitoring, and improved health outcomes that reduce long-term healthcare costs. IoT-enabled healthcare systems improve access to medical services while reducing emergency interventions and hospital readmissions.

7.3. Cost Savings And Efficiency Gains

Smart city technologies generate significant cost savings across government operations, with cities reporting 5-15% reductions in operational expenses through automation and optimization. Energy management systems alone can reduce municipal energy costs by 20-30% through demand optimization and renewable energy integration. Predictive maintenance systems reduce infrastructure maintenance costs by 10-15% while extending asset lifecycles and improving service reliability. These systems prevent costly emergency repairs and optimize

maintenance scheduling based on actual asset conditions rather than predetermined schedules.

Administrative efficiency improvements through digital governance systems reduce processing times by 30-50% while improving service quality and citizen satisfaction. Automated systems handle routine transactions, freeing human resources for complex problem-solving and citizen engagement activities.

8. IMPLEMENTATION CHALLENGES AND SOLUTIONS

8.1. Infrastructure And Investment Barriers

Infrastructure limitations represent the most significant challenge for smart city implementation, particularly in developing countries where 85% of cities face inadequate ICT infrastructure. These limitations include insufficient broadband connectivity, unreliable electricity supply, and lack of skilled technical personnel. High initial investment costs create barriers for many cities, with 78% of developing country implementations struggling with funding requirements. Solutions include phased implementation approaches, public-private partnerships, and international development assistance programs that spread costs over extended timeframes.

Digital infrastructure gaps in developing countries involve both access and affordability challenges, with smartphone penetration rates as low as 31% in Pakistan, 38% in Nigeria, and 47% in India. These gaps require targeted interventions including device subsidies, affordable connectivity programs, and digital literacy initiatives.

8.2. Digital Divide And Inclusion

The digital divide poses significant challenges for inclusive smart city development, with many residents lacking stable or affordable internet access. This exclusion prevents portions of the population from accessing digital services that are core to smart city functionality.

Gender disparities in technology access create additional barriers, with women facing systemic obstacles to accessing and utilizing digital technologies. These disparities require targeted interventions including women-focused digital literacy programs, affordable device access, and culturally appropriate technology design.

Age-related digital exclusion affects elderly populations who may lack the skills or confidence to engage with digital interfaces. Smart cities must provide alternative service delivery methods and age-appropriate technology training to ensure inclusive access.

8.3. Security And Privacy Concerns

Data security and privacy concerns represent critical challenges for smart city implementation, with over 50,000 cyber-attacks on government systems documented in 2023. Cities must implement robust cyber security frameworks and data governance policies to protect citizen information. Interoperability issues between different systems create technical and security vulnerabilities. Solutions include adoption of open standards, development of secure APIs, and implementation of comprehensive system integration protocols. Trust in digital systems remains a significant barrier, requiring transparent data governance, citizen engagement in policy development, and clear communication about data use and protection measures. Cities must balance innovation opportunities with privacy protection and citizen rights.

9. DIGITAL INCLUSION STRATEGIES

9.1. Bridging The Digital Divide

Effective digital inclusion strategies require comprehensive approaches addressing infrastructure, affordability, and digital literacy simultaneously. Cities must ensure that smart city benefits reach all residents, regardless of socioeconomic status, age, or technical capability. Digital literacy programs provide essential skills training for citizens to effectively engage with smart city services. These programs must be culturally appropriate, accessible to diverse populations, and integrated with existing community services and educational institutions.

Affordable connectivity initiatives, including public Wi-Fi networks, device lending programs, and subsidized internet access, ensure that economic barriers do not prevent digital participation. Cities like Manchester have implemented successful digital inclusion programs including Go ON Manchester and East Serve.

9.2. Community Engagement And Participation

Citizen-centric smart city development requires ongoing community engagement to ensure technology implementations meet actual resident needs. Participatory design processes involve citizens in technology planning and implementation decisions.

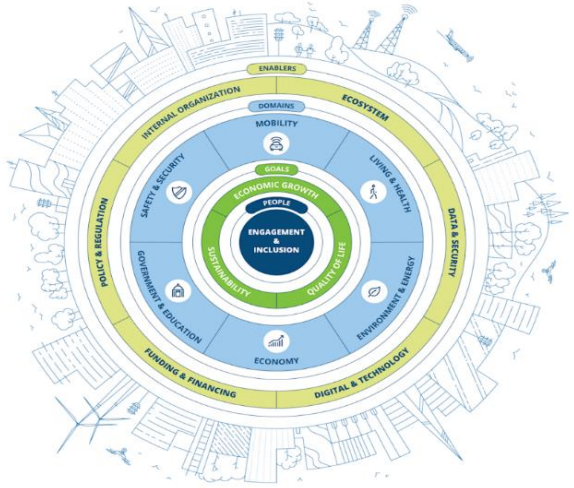

Figure.7.Citizen-centric framework outlining six enablers driving smart city initiatives, including digital technology, data security, and ecosystem collaboration, aimed at economic growth, sustainability, and quality of life

Digital platforms enable citizen participation in governance through online consultation, collaborative planning, and feedback mechanisms. Cities like Bristol utilize citizen feedback through initiatives such as the Bristol Open Data energy challenge and digital idea laboratories. Cultural adaptation ensures that smart city technologies respect local values, traditions, and social structures. Implementation strategies must consider cultural context to avoid technological solutions that conflict with established community practices.

9.3. Accessibility And Universal Design

Universal design principles ensure that smart city technologies are accessible to people with disabilities and diverse functional capabilities. This includes visual, auditory, motor, and cognitive accessibility considerations in all digital interfaces and physical infrastructure.

Multi-modal service delivery provides alternative access methods for citizens who cannot or prefer not to use digital interfaces. These alternatives include telephone services, in-person assistance, and simplified digital interfaces designed for varying technical capabilities. Language accessibility ensures that smart city services are available in multiple languages reflecting community diversity. This includes translated interfaces, multilingual support services, and culturally appropriate communication strategies.

10. CASE STUDIES AND BEST PRACTICES

10.1. Singapore: Integrated Smart Nation Initiative

Singapore represents a global leader in comprehensive smart city implementation, demonstrating how ICT infrastructure can enhance urban sustainability while maintaining high quality of life. The city-state has achieved the world's highest urban tree density with two million trees, integrating green infrastructure with advanced technology systems. Singapore's smart water recycling systems utilize IoT sensors to monitor water quality and optimize distribution networks, ensuring efficient resource utilization while maintaining water security. The integrated approach includes AI-driven urban planning that optimizes traffic flow, energy distribution, and resource management across the entire city-state.

The National Digital Identity system provides citizens with secure, convenient access to government services while maintaining privacy protection. This system demonstrates how digital infrastructure can enhance service delivery while building citizen trust in technology implementations.

10.2. London: Data-Driven Urban Management

London's Smart London Plan demonstrates how major cities can leverage open data and citizen engagement to drive innovation and improve services. The city has implemented comprehensive data sharing through the London Data Store, providing public access to datasets from multiple government departments. The transport system innovations include congestion charging, Oyster smart ticketing, and real-time travel information that have transformed urban mobility. Transport for London utilizes Oyster card data in collaboration with UCL to understand congestion patterns and plan future investments. Borough-level innovations show how local governments can achieve significant efficiency gains through digital transformation. The Borough of Newham increased online service delivery from 9% to 64% in one year, achieving £11 million in savings while improving service accessibility.

10.3. Manchester: People-Centered Innovation

Manchester's approach to smart city development emphasizes digital inclusion and citizen-centered innovation. The Manchester Digital Development Agency implements initiatives that prioritize people-centered solutions over technology-driven approaches. Digital inclusion programs including Go ON Manchester and EastServe specifically target residents who lack digital access or skills. These programs demonstrate how cities can ensure that smart city benefits reach all residents, not just those who are already digitally connected.

The Manchester Living Lab enables citizen participation in planning the city's future through collaborative innovation processes. This approach ensures that technology implementations address actual citizen needs rather than imposing solutions developed without community input.

11. FUTURE DIRECTIONS AND EMERGING TRENDS

11.1. Next-Generation Technologies

Emerging technologies including edge computing, blockchain, and digital twins are transforming smart city capabilities. Edge computing enables real-time processing of IoT data, reducing latency and improving responsiveness for critical applications like autonomous vehicles and emergency response systems. Blockchain technology provides secure, transparent data management for smart city applications, enabling trusted data sharing between multiple stakeholders while maintaining privacy protection. Distributed ledger systems can facilitate new forms of citizen participation in urban governance and resource sharing.

Digital twins create virtual representations of urban systems that enable simulation, scenario modeling, and predictive planning. These systems allow city planners to test interventions and optimize urban systems before implementation, reducing risks and improving outcomes.

11.2. Autonomous Infrastructure

The development of autonomous infrastructure systems represents the next evolution of smart cities, with self-maintaining buildings, automated transportation networks, and adaptive energy systems. These systems utilize AI and machine learning to operate independently while optimizing performance and efficiency. Autonomous vehicles and intelligent transportation systems will transform urban mobility, reducing congestion, emissions, and infrastructure requirements. Integration with smart city infrastructure enables coordinated traffic management and optimized routing based on real-time conditions.

Self-maintaining infrastructure utilizes predictive analytics and automated repair systems to maintain optimal performance with minimal human intervention. These systems reduce maintenance costs while improving service reliability and extending asset lifecycles.

11.3. Cognitive Cities Evolution

The transition from smart cities to cognitive cities represents a fundamental shift toward predictive, adaptive urban systems. Cognitive cities utilize artificial intelligence to anticipate citizen needs, predict system failures, and optimize resource allocation proactively rather than reactively. 5G-enabled cognitive computing facilitates real-time collaboration between urban systems, enabling holistic decision-making that considers multiple impacts and stakeholder needs. These systems can analyze multi-dimensional consequences of

decisions and optimize outcomes across multiple urban domains simultaneously.

Collaborative decision-making systems integrate citizen input, expert knowledge, and data analytics to support transparent, inclusive urban governance. These systems enable participatory democracy while leveraging technological capabilities to improve decision quality and implementation effectiveness.

12. CONCLUSIONS AND RECOMMENDATIONS

12.1. Key Findings

This research demonstrates that ICT-enabled smart cities represent a transformative approach to sustainable urban development, offering significant opportunities for economic growth, environmental sustainability, and social inclusion. The global smart city ICT infrastructure market's projected growth from $1.67 trillion in 2024 to over $9 trillion by 2033 reflects the massive scale of this transformation. IoT applications across transportation, energy, healthcare, and governance domains provide measurable benefits including 15-30% improvements in operational efficiency, 10-15% cost reductions, and significant enhancements in service quality. These technologies enable data-driven decision-making that optimizes resource allocation while improving citizen experiences.

However, successful implementation requires addressing significant challenges including infrastructure limitations, digital divides, and security concerns. Cities must adopt inclusive approaches that ensure technology benefits reach all residents while protecting privacy and maintaining democratic governance.

12.2. Policy Recommendations

Governments should prioritize public-private partnerships that leverage private sector innovation while maintaining public oversight and social responsibility. These partnerships can address funding challenges while ensuring that smart city implementations serve public interests rather than purely commercial objectives. Digital inclusion policies must be integrated into all smart city planning processes, ensuring that technology implementations enhance rather than exacerbate existing inequalities. This includes targeted programs for elderly residents, people with disabilities, and economically disadvantaged communities.

Regulatory frameworks should balance innovation encouragement with privacy protection, security requirements, and citizen rights. Regulatory sandboxes can enable experimentation with new technologies while maintaining appropriate oversight and risk management.

13. Future Research Directions

Future research should focus on measuring long-term impacts of smart city implementations on social equity, environmental sustainability, and economic development. Longitudinal studies are needed to understand how technology implementations affect different population groups over time. Comparative analysis of different smart city models and implementation approaches can provide insights into effective strategies for diverse urban contexts. Research should examine how local conditions, governance structures, and cultural factors influence smart city success.

Development of standardized metrics and evaluation frameworks will enable better comparison of smart city initiatives and identification of best practices. These frameworks should integrate quantitative performance measures with qualitative assessments of citizen satisfaction and social outcomes. The convergence of ICT infrastructure, sustainable development, and inclusive governance presents unprecedented opportunities for creating urban environments that serve both human needs and environmental sustainability. Success requires coordinated efforts across technology development, policy innovation, and community engagement to ensure that smart cities fulfill their promise of enhanced quality of life for all urban residents

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Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

Revolutionizing Supply Chains: Digital Transformation in Aviation and Pharmaceuticals

Ansari Mohammad Muzammil Parvez Ahmed[a*], Akraan Mohammed Ali Sayyed[b], Maryam Hanzala Tariq[c]

[a,b,c]*A.I.'s Allana Institute of Management Studies Affiliated to University of Mumbai*

*Email: 2325133.ansari.muzammil@aiaims.edu.in

ABSTRACT

This research explores how digital transformation is reshaping supply chains in the aviation and pharmaceutical industries. With the widespread implementation of technologies like blockchain, IoT, and cloud computing, companies are improving efficiency, transparency, and resilience in their operations. In aviation, predictive maintenance, real-time tracking, and data integration help reduce downtime and enhance performance, as seen in initiatives by Air India Engineering Services Ltd. (AIESL). Similarly, the pharmaceutical sector relies on blockchain for drug traceability, IoT sensors for cold-chain logistics, and cloud platforms for collaboration to ensure compliance and product integrity. While these advancements bring significant benefits, industries still face problems such as high cost of implementation, cybersecurity risks, and the need for skilled professionals to manage these technologies. By overcoming these roadblocks, businesses can fully harness the potential of digital transformation to build smarter, more secure, and more efficient supply chains for the future.

Keywords: aviation, pharmaceutical, supply chain, digital transformation

1. INTRODUCTION

In today's rapidly evolving technological landscape, digital transformation has become a crucial factor in optimizing supply chain management (SCM) across various industries. The aviation and pharmaceutical sectors, both of which rely on complex global supply chains, are leveraging digital solutions to enhance efficiency, ensure compliance, and improve overall operational resilience. As a student researcher, this study explores how these industries adopt cutting-edge technologies such as blockchain, Internet of Things (IoT), cloud computing, and cybersecurity solutions to address their unique challenges.

1.1. Digitalization in the Aviation Sector

The aviation industry requires high levels of operational efficiency, safety, and asset management to ensure smooth global logistics. Companies such as Air India Engineering Services Ltd. (AIESL) are implementing predictive maintenance systems, IoT-enabled tracking, and cloud-based inventory management to optimize aircraft maintenance and reduce downtime. Enterprise software like SAP ERP, IBM Maximo, and Airbus Skywise plays a crucial role in enabling data-driven decision-making and improving supply chain visibility. To support these digital efforts, the aviation sector increasingly relies on rugged technology, including Panasonic Toughbooks, Dell Rugged Latitude laptops, and Zebra enterprise tablets, which allow technicians to access maintenance logs, real-time inventory data, and diagnostic tools in demanding environments. These devices help engineers work efficiently in airports, maintenance hangars, and outdoor locations, ensuring seamless documentation and workflow automation. However, as aviation operations become more digital, cybersecurity has emerged as a critical concern. The integration of firewall software such as Fortinet FortiGate, Cisco Firepower, and Palo Alto Networks helps protect sensitive supply chain data, flight maintenance records, and operational networks from cyber threats. With intrusion detection systems (IDS), multi-factor authentication (MFA), and encryption protocols, aviation companies are fortifying their networks against unauthorized access. Despite these advancements, high implementation costs, cybersecurity risks, and the need for skilled personnel remain challenges that must be addressed for sustainable digital adoption.

1.2. Digitalization in the Pharmaceutical Sector

The pharmaceutical industry faces distinct challenges in supply chain management, including drug traceability, regulatory compliance, and cold-chain logistics. Digital transformation is playing a crucial role in overcoming these obstacles by ensuring real-time monitoring, secure data exchange, and automated compliance reporting. Many pharmaceutical companies are adopting blockchain technology for drug traceability, IoT sensors for temperature monitoring, and cloud-based platforms for data sharing among manufacturers, distributors, and regulators. Software solutions like SAP Integrated Business Planning (IBP), Oracle SCM Cloud, and TraceLink are widely used to enhance demand forecasting, regulatory reporting, and inventory management. Additionally, rugged technology is increasingly utilized to improve efficiency in warehouses, distribution centers, and manufacturing plants. Devices such as Honeywell Dolphin scanners, Zebra rugged tablets, and Getac laptops allow logistics personnel and quality control teams to manage shipments, scan barcodes, and track inventory in real-time, even under extreme conditions. Given the highly sensitive nature of pharmaceutical supply chains, data protection and cybersecurity are essential. Companies employ firewall solutions like Check Point, Sophos XG Firewall, and Palo Alto Networks to safeguard intellectual property, patient data, and regulatory compliance records. Further, AI-driven security monitoring, encrypted cloud storage, and multi-layer authentication ensure protection against data breaches and cyberattacks. However, challenges such as high technology costs, integration with legacy systems, and workforce training remain key barriers to digital transformation in this sector. Before digital transformation, managing supply chains in the aviation and pharmaceutical industries was a slow, manual process filled with inefficiencies and risks. Everything from tracking parts and inventory to ensuring regulatory compliance relied heavily on paper records, phone calls, and spreadsheets, making operations less responsive and more prone to human error.

1.3. Objectives of the Research

- To explore the digital transformation in the aviation & pharmaceutical sector.

• To understand the digital implementation challenges faced by the aviation and pharmaceutical industries

2. INDUSTRIES BEFORE DIGITAL TRANSFORMATION

2.1. Aviation Sector

Before the emergence of breakthrough technologies, handwritten maintenance logs were used, and aircraft technicians recorded maintenance updates in physical logbooks, making it difficult to track repairs and sometimes leading to misplaced records or outdated information. Furthermore, airlines followed a method of scheduled maintenance instead of predictive maintenance. Airlines followed fixed maintenance schedules rather than monitoring real-time aircraft conditions, often resulting in unexpected breakdowns and longer grounding times. Spare parts were tracked manually, requiring staff to call different suppliers or check warehouses physically, increasing delays and inefficiencies. The coordination between maintenance crews, suppliers, and logistics teams relied on emails and phone calls, leading to miscommunication and slower response times. Since most operations were offline, security threats weren't a major concern. However, reliance on physical documents increases the risk of misplaced or tampered records.

2.2. Pharmaceutical Sector

Tracking medicines from production to delivery was done using paper logs, making it difficult to detect counterfeit drugs or track expired batches. Manufacturers, distributors, and regulators worked in silos, relying on separate systems that didn't communicate well, often leading to delays and mismanaged inventory. Furthermore, Temperature-sensitive medications were transported with minimal real-time monitoring, increasing the risk of spoilage before reaching patients. Production and inventory decisions were based on past sales trends rather than real-time data, making it harder to balance supply with actual demand. Additionally, checking shipments for compliance and quality involved physical inspections, increasing processing times and the chances of human error. In both industries, the lack of automation, real-time data, and system integration made supply chains more vulnerable to delays, mistakes, and regulatory risks. Digital transformation has changed the game by introducing smart tracking, automation, and data-driven decision making, making supply chains more efficient, secure, and adaptable to modern challenges.

3. RESEARCH METHODOLOGY

This research adopts an extensive secondary data analysis to examine the impact of digital transformation on supply chain management (SCM) in the aviation and pharmaceutical industries. The study explores how emerging technologies, including blockchain, IoT, cloud computing, AI-driven analytics, and cybersecurity solutions, enhance operational efficiency, traceability, and resilience in SCM. It also incorporates real-world case studies, statistical models, and industry insights to ensure a practical, academically robust analysis.

3.1. Research Design:

This study follows an exploratory research design: 4 | P a g e o Investigates current trends, emerging technologies, and digital adoption challenges in SCM. o Detailed case study analysis on AIESL (aviation) and Pfizer/Moderna (pharmaceuticals) to understand real-world applications.

3.2. Sampling Method:

A purposive sampling strategy is used to select industry experts and SCM professionals for data collection. The study targets:

• Aviation Industry: Professionals from AIESL, Boeing, Airbus, and MRO service providers to understand digital SCM adoption in fleet maintenance, spare parts logistics, and predictive analytics.

• Pharmaceutical Industry: Supply chain managers from Pfizer, Moderna, Novartis, and regulatory bodies to analyze digital solutions in drug traceability, cold-chain management, and compliance.

3.3. SOURCES OF DATA

3.3.1. Primary Data

The researcher conducted semi-structured interviews with supply chain professionals, IT experts, and cybersecurity specialists. The Surveys/questionnaires were distributed to aviation and pharmaceutical industry personnel to collect quantitative data on SCM efficiency, cost reduction, and cybersecurity concerns.

3.3.2. Secondary Data:

Secondary data sources include industry reports from McKinsey, Deloitte, PwC, and Gartner on SCM digitalization trends, case study of AIESL, Pfizer, and Novartis for examining digital SCM implementation success factors. The author also reviewed secondary data from academic journals, research papers, and whitepapers from SCM software providers (SAP, Oracle, IBM Blockchain, Microsoft Azure IoT).

3.4. Secondary Data Analysis

Digital transformation in supply chain management (SCM) is playing a crucial role in modernizing operations across industries. The aviation and pharmaceutical sectors, in particular, are adopting technologies such as blockchain, IoT, cloud computing, rugged 5 | P a g e technology, and cybersecurity solutions to address challenges like global logistics, compliance, and operational efficiency. This section reviews existing research, industry reports, and real-world case studies on these technologies.

3.5. Digital Transformation In Aviation Supply Chains

The aviation industry requires real-time tracking, predictive maintenance, and effective spare parts management to reduce aircraft downtime and ensure safety. Several studies have analyzed the impact of digital transformation on supply chain efficiency.

3.5.1. Predictive Maintenance And Iot Integration

According to Ding, Zhao, & Jin (2022), predictive maintenance in aviation is enabled by IoT sensors that continuously monitor engine wear, temperature, and vibration. Air India Engineering Services Ltd. (AIESL) has adopted IoT-driven predictive analytics to identify potential failures before they occur,

reducing aircraft maintenance time and preventing flight cancellations (AIESL Annual Report, 2023).

3.5.2. Real-Time Inventory Management & Cloud Solutions

Cloud-based inventory management systems are improving supply chain visibility. A study by Lufthansa Technik (2021) found that airlines using SAP Aerospace & Defense Industry Solution experienced better spare parts tracking and forecasting accuracy. RFID and GPS based tracking further enhance inventory control (Kumar et al., 2022).

3.5.3. Use Of Rugged Technology In Maintenance & Logistics

Field studies by Honeywell Aerospace (2023) reveal that rugged laptops and tablets, such as Panasonic Toughbooks and Zebra TC57 handheld scanners, are being deployed in aircraft hangars to assist with maintenance. These devices withstand harsh environmental conditions, extreme temperatures, and high-impact use, making them ideal for on-site aircraft maintenance and parts tracking.

3.5.4. Cyber security And Data Protection In Aviation

SCM The aviation industry is a target for cyberattacks, making firewall protection and secure data sharing platforms critical. According to a report by the International Civil Aviation Organization (ICAO, 2022), airlines and maintenance organizations are implementing Palo Alto Networks, Cisco Firepower, and Fortinet firewalls to secure aircraft maintenance records, real-time tracking systems, and operational databases..

3.6. Digital Transformation In Pharmaceutical Supply Chains

Pharmaceutical SCM requires strict regulatory compliance, traceability, and temperature controlled logistics. Studies and industry reports have analyzed how digital solutions are improving these areas.

3.6.1. Block chain For Drug Traceability & Counterfeit

Prevention Counterfeit drugs pose a major threat to public health. The World Health Organization (WHO, 2021) states that 10% of medicines in developing nations are counterfeit. To combat this, pharmaceutical giants Pfizer, Novartis, and Merck have deployed blockchain-based traceability solutions using platforms like IBM Food Trust and TraceLink (Kshetri, 2021). This ensures secure, tamper-proof tracking of drugs, in compliance with DSCSA (Drug Supply Chain Security Act) and the EU Falsified Medicines Directive (FMD).

3.6.2. Iot Sensors In Cold-Chain Logistics

IoT solutions are improving the efficiency of temperature-controlled pharmaceutical logistics. Singh et al. (2022) examined how IoT-enabled packaging sensors and RFID-based tracking help maintain temperature stability for vaccines and biologics. Companies such as Moderna and BioNTech use Cloudleaf and TempTime IoT sensors to track real-time shipment conditions (McKinsey & Co., 2023).

3.6.3. Cloud-Based Supply Chain Management In Pharmaceuticals

Pharmaceutical firms are adopting cloud-based planning and AI-driven forecasting for supply chain management. A report by McKinsey & Co. (2023) shows that companies using SAP Integrated Business Planning (IBP) and Oracle SCM Cloud have experienced 20-30% improvements in supply chain efficiency. Cloud-based platforms enable faster coordination between manufacturers, suppliers, and distributors (Gartner, 2022).

3.6.4. Use Of Rugged Technology In Pharma Warehouses

Rugged devices are being integrated into warehouse management to streamline pharmaceutical inventory tracking. A Deloitte (2022) case study found that pharmaceutical logistics teams using Zebra MC9300 and Honeywell Dolphin CT60 rugged barcode scanners improved inventory accuracy and reduced human errors. These devices integrate with SAP and Oracle supply chain systems, ensuring seamless data synchronization (PwC, 2022).

3.6.5. cyber security In Pharmaceutical Scm

With increasing digitalization, cybersecurity threats to pharmaceutical supply chains are on the rise. A report by the U.S. Food and Drug Administration (FDA, 2023) warns of data breaches and ransomware attacks targeting clinical trial records and regulatory compliance data. Leading pharmaceutical firms are deploying firewall security (Check Point, Sophos XG), AI-driven security analytics, and encrypted cloud storage to protect sensitive supply chain data (Forrester, 2023)
After extensive literature review analysis, the following can be identified as the key challenges in digital supply chain adoption:

- High Implementation Costs: Research by Accenture (2023) highlights that IoT infrastructure, cloud migration, and cybersecurity investments remain expensive, especially for small and mid-sized enterprises (SMEs).
- Cybersecurity Risks: Reports from IBM Security (2022) indicate that aviation and pharmaceutical supply chains are prime targets for cyberattacks, ransomware threats, and data theft.
- Workforce Training & Adoption Barriers: A study by Boston Consulting Group (BCG, 2023) found that only 40% of supply chain employees receive proper training on digital transformation tools.
- Integration with Legacy Systems: Many companies struggle to integrate modern digital SCM platforms with existing legacy ERP systems, creating operational inefficiencies (Gartner, 2022).

3.6.6. Primary Data Analysis & Findings:

From tables 1 & 2, the following can be inferred:

- Both industries acknowledge the efficiency improvements with digital supply chains.
- Pharmaceutical professionals see digital tools as highly effective for demand forecasting and drug traceability.
- Aviation experts value tracking spare parts, but sourcing delays remain a challenge.

- Real-time data helps in decision-making for both industries.
- Training on digital tools is considered "adequate" but not "comprehensive." 8 | P a g e
- Government policies support digital transformation, but execution lags.
- • While digital systems reduce mistakes in ordering, their adoption is not yet seamless.

Major Challenges Identified:

- Sourcing raw materials and spare parts remains a weak point.
- Support teams respond to issues, but delays are common.
- India's digital supply chains are still catching up to global standards.

Table.1.Responses from pharmaceutical Industry

S. No.	Statement	Mean Score
1	Digital supply chains have made pharmaceutical operations more efficient.	4.1
2	Medicine delivery times have improved with digital supply chain systems.	3.9
3	Digital tools help forecast the demand for medicines.	3.9
4	Tracking drug inventory is simple with digital systems.	3.7
5	Sourcing raw materials is quicker using digital supply chain solutions.	3.3
6	Real-time data aids in better production and distribution decisions.	3.9
7	Merging digital supply chains with old processes is difficult.	4
8	Training on digital tools for managing pharmaceutical logistics is sufficient.	3.4
9	Digital systems reduce mistakes in ordering medicines.	3.9
10	Support teams address digital supply chain issues promptly.	3.7
11	India's pharmaceutical digital supply chains match global standards.	3.4
12	Raw material shortages affect pharmaceutical production due to supply chain issues.	4.4
13	Stronger digital tools are needed to manage medicine stocks in India.	4.6
14	Government policies encourage digital innovation in pharmaceutical supply chains.	3.7
15	The future of pharmaceutical logistics in India relies on better digital systems.	4.4

Table.1.Responses from Aviation Industry

Sr No.	Statement	Mean Score
1	Digital Supply Chain Transformation has improved aircraft maintenance efficiency.	3.7
2	Using digital supply chain systems helps reduce aircraft downtime.	3.5
3	Digital Supply Chain Transformation helps predict when spare parts will be needed.	3.4
4	Tracking spare parts using digital systems is easy and reliable.	3.9
5	Getting spare parts is faster due to Digital Supply Chain Transformation.	3
6	Real-time data from digital systems helps in better maintenance decision-making.	3.7
7	Integrating new digital supply chain solutions with old maintenance processes is challenging.	4.3
8	We receive adequate training on digital supply chain tools for maintenance.	3.4
9	Digital systems help in reducing errors in spare part ordering.	3.9
10	Support teams respond quickly when there is a digital supply chain issue.	3.5
11	Digital Supply Chain Transformation in India is at par with global aviation standards.	3.1
12	There is a shortage of locally available aircraft parts due to supply chain issues.	4.1
13	Indian aviation needs better digital supply chain systems for tracking and managing spare parts.	4.4
14	Government policies in India support the adoption of Digital Supply Chain Transformation in aviation.	3.4
15	The future of aircraft maintenance in India depends on better Digital Supply Chain Transformation.	4.4

4. SUGGESTIONS AND RECOMMENDATIONS:

Based on the findings of this research, several key recommendations can be made to enhance digital transformation in supply chain management (SCM) for the aviation and pharmaceutical industries.

4.1. Strengthening Technological Integration

- Aviation Industry: Companies should invest in predictive analytics and AI-driven forecasting to optimize spare parts availability and reduce maintenance downtime. Expanding digital twin technology can further enhance operational efficiency.
- Pharmaceutical Industry: Adoption of blockchain for end-to-end drug traceability should be accelerated to minimize counterfeit risks. Expanding IoT-based temperature monitoring systems will improve cold-chain logistics.

4.2. Addressing Implementation Challenges

- Overcoming Integration Barriers: Many companies struggle to merge new digital tools with legacy systems. A phased transition approach, integrating cloud-based middleware solutions, can ease this process.
- Cost Management: High upfront investment costs hinder digital adoption. Implementing subscription-based digital SCM models (SaaS) can reduce initial capital expenditure and encourage widespread adoption.

4.3. Enhancing Workforce Readiness

- Skill Development: Digital SCM success depends on trained professionals. Organizations should collaborate with universities and industry bodies to offer certifications in digital supply chain management, AI, and cyber security.
- Change Management: Implement structured training programs and workshops to ensure smooth adoption of new technologies across teams.

4.4. Improving Cybersecurity Measures

- Stronger Data Protection Policies: Since digital SCM systems handle sensitive data, companies must enhance firewall security, end-to-end encryption, and multi-factor authentication.
- Regulatory Compliance: Companies should adopt globally recognized cybersecurity frameworks such as ISO 27001 and NIST to mitigate risks.

5. STRENGTHENING GOVERNMENT POLICIES AND INDUSTRY COLLABORATION

- Policy Reforms: Governments should provide incentives for companies investing in digital SCM solutions, such as tax benefits and grants for AI-driven logistics projects.
- Industry Partnerships: Increased collaboration between aviation and pharmaceutical companies, tech providers, and policymakers will accelerate digital adoption. Establishing public-private partnerships can facilitate research and development in digital supply chains.

6. CONCLUSION

The aviation and pharmaceutical industries must accelerate digital transformation to enhance efficiency, traceability, and resilience. By addressing integration challenges, investing in workforce training, improving cybersecurity, and fostering industry collaboration, organizations can unlock the full potential of digital supply chains and achieve long-term supply chain optimization and sustainability.

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Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

Phytochemicals, Anti-oxidant and In-vitro Anti-diabetic Activities of Aqueous and Boiled Leaf Extracts of *Thaumatococcus daniellii*

Ngaitad Stanislaus Njinga[a*], Ache Roland Ndifor[b], Abiodun Oyetunji Shittu[c], Lawal Muhammadbashir[d], Samuel Oluwasegun Kayode[e]

[a]*Department of Pharmaceutical and Medicinal Chemistry, University of Ilorin, Ilorin, Nigeria.*
[b]*Higher Technical Teacher Training College, University of Bamenda, Cameroon*
[c,]*Department of Pharmaceutics and Industrial Pharmacy, University of Ilorin, Ilorin, Nigeria.*
[d,e]*Faculty of Pharmaceutical Sciences, University of Ilorin, Ilorin, Nigeria.*
*E:mail: ngastanjin@yahoo.com

ABSTRACT

Thaumatococcus daniellii, commonly known as the "miracle fruit plant," is renowned for its diverse phytochemical composition and health-promoting properties. Traditionally, its leaves are used in culinary practices, serving as natural food wrappers and flavor enhancers. Beyond its culinary applications, the plant is also valued for its potent antioxidant and anti-diabetic potential, which has attracted scientific interest. However, despite its long-standing use, limited studies have explored the specific health benefits of Thaumatococcus daniellii in different preparation methods. This study aims to evaluate the phytochemical constituents, antioxidant activities, and in vitro anti-diabetic effects of two preparations of the plant—the fresh-boiled extract (FBE) and dried aqueous leaf extract (DAE). Phytochemical analysis was performed using a spectrophotometric method, while antioxidant activities were assessed using DPPH, ABTS, FRAP, PMA, and metal chelation activity (MCA) assays. The anti-diabetic potential was evaluated through α-amylase inhibition assays. Results showed that the FBE contained lower levels of flavonoids (0.368 mg QE/g) and alkaloids (642.44 mg AE/g) compared to the DAE (0.472 mg QE/g and 665.78 mg AE/g). However, FBE exhibited higher tannin (278.13 mg TAE/g) and phenol (0.048 mg GAE/g) concentrations. In antioxidant activities, the FBE showed higher DPPH scavenging (36.72%) and FRAP (0.1895 mg Fe2+/g), while the DAE had better PMA activity (0.069 mg AAE/g). The anti-diabetic potential of DAE (55.56%) was significantly higher than that of FBE (12.82%), indicating boiling reduces α-amylase inhibition. In conclusion, Thaumatococcus daniellii demonstrates significant health-promoting properties in both FBE and DAE, supporting its value for culinary and therapeutic applications.

Keywords: Thaumatococcus daniellii leaves, Comparative phytochemistry, Antioxidant activity, Anti-diabetic activity

1. INTRODUCTION

The sweet prayer plant, or *Thaumatococcus daniellii*, is a perennial herb indigenous to tropical Africa (Agha et al., 2022). It is renowned for its economic and medicinal significance, primarily due to its leaves and the thaumatin protein extracted from its fruit, which is widely used as a natural sweetener (Chinedu et al., 2022). In Nigeria and other parts of West Africa, the leaves of *T. daniellii* are traditionally used as natural wrappers for cooking and preserving food, imparting a distinct flavor and aroma to local delicacies such as moi-moi (steamed bean pudding) and ofada rice (Yusli et al., 2023).

This study compares the phytochemical composition, antioxidant capacity, and in-vitro anti-diabetic activities of aqueous and boiled leaf extracts of *T. daniellii* in order to determine the best preparation methods that maximize the plant's therapeutic potential. The results of this study could provide a scientific basis for the use of *T. daniellii* in traditional cuisines as well as in medicine and its development into functional foods or pharmaceuticals for managing oxidative stress and diabetes.

2. MATERIALS AND METHODS

2.1. Collection of Plant Material

Thaumatococcus daniellii leaves were sourced from the Kunlende Market, Ilorin, Kwara state, Nigeria and identified properly by a botanist, Dr. Bolu, a taxonomist in the Department of Plant Biology, University of Ilorin, Nigeria, and a Voucher Number *UILH/006/1237* deposited.

2.2. Preparation and Extraction

2.2.1. Dried leaves extraction

The dried leaf of *Thaumatococcus daniellii*, were pounded using a mortar and pestle for size reduction. 167.8g of the finely ground dried leaves stock were placed in an extraction bottle and to it, 2000 mL of distilled water was added and the bottle was capped. This was then left to stand for 24 hours after which the extract was strained using a stainer. The strained extract was then placed in a crucible and placed on top of a water bath at 40 ^{o}C to be concentrated. Once fully dried, the dried aqueous extract (DAE) was scraped off and weighed.

2.2.2. Fresh Boiled Leaves Extraction

To extract fresh leaves, 215g of fresh leaves were placed in a clean boiling pot and to it, 1500 mL of distilled water was added and heated to 100 °C for 90 min to simulate the culinary act. This was then left to cool and then, the extract was strained. The extracts were then placed on a crucible and dried over a water bath at 40 ^{o}C after which the fresh boiled extract (FBE) was scrapped and weighed. The percentage yield for each extract was calculated using the formula:

$$\text{Percentage yield} = \frac{\text{Weight of extract}}{\text{Weight of powdered plant material}} \times 100$$

3. QUANTITATIVE PHYTOCHEMISTRY

All test were carried out at concentration of 0.01 mg of extract and were all done in triplicates

Total Phenolic Content (TPC) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

1 mL of Folin reagents and 0.8 mL of sodium carbonate (75 %w/v) was added to 1 mL (56 µL of sample + 944 µL of

distilled water) of the BFE and DAE of *Thaumatococcus danielli* and left on standing for 60 minutes at room temperature. After which the absorbance was taken at 765 nm using a UV Vis spectrophotometer and the results was recorded (Njinga et al., 2024; Abdulaziz *et al.,* 2024). All test were carried out at concentration of 0.01 mg of extract

Total Flavonoid Content (TFC) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

To the 500 µL (50 µL of extract + 450 µL of distilled water) of the BFE DAE BFE and DAE of *Thaumatococcus danielli*, 2 mL of aluminium chloride(10 %w/v) was added, shaken and kept at room temperature for 30 minutes. All test were carried out at concentration of 0.01 mg of extract The absorbance of the reaction mixture after 30 minutes was taken at 420 nm (Njinga et al., 2024; Abdulaziz *et al.,* 2024).

Total Tannin Content of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

To the 200 µl (44 µl + 15 µl of distilled water) of the boiled and dried test samples, Catechin and 1.5ml of reagents (5g Vanillin and 8% concentrated HCL; 1:1 in methanol) mixture was added and incubated at room temperature for 20 minutes and absorbance was taken at 500 nm using UV-Vis spectrophotometer (Njinga et al., 2024).

Total Alkaloid content (TAC) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

To 100 µL (42 µL of sample + 58 µL of distilled water) of the boiled and dried extract, 1 mL of BCG reagent was added and then, to it, 1 ml of Na_3PO_4 Buffer. The resulting solution was extracted with 2mls of chloroform ($CHCL_3$) and the absorbance was taken at 570 nm using a UV-VIS Spectrophotometer. All tests were performed in triplicates for both the boiled and dried extract (Jatav and Tenguria, 2022).

Total Saponin content (TSC) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

To 500 µL (120 µL of sample + 380 µL of distilled water) of the boiled and dried extract, 0.5 µL of 80% vanillin in ethanol and 5 µL of 72% distilled H_2SO_4 were added. The resulting solution was heated in a water bath at 60 °C for 10 minutes and cooled in ice H_2O. The absorbance was taken at 535 nm using a UV-Vis Spectrophotometer. The saponin concentration was reported as Quillaja saponin equivalents per gram of sample dry matter (µg QSE/g DM), with Quillaja saponin (Sigma-Aldrich) acting as a reference (Shiau et al., 2009). All tests were performed in triplicates for both the boiled and dried extract (Ozay and Mammadov, 2019). Ozay, C., & Mammadov, R. (2019). Antioxidant activity, total phenolic, flavonoid and saponin contents of different solvent extracts of Convolvulus phrygius. *Bornm. Curr. Pers. MAPs*, *2*(1), 23-28.

3.1. Antioxidant Assay

All antioxidant assay were carried out at concentration of 0.01 mg of extract and were all done in triplicates

DPPH Radical Scavenging Activity (DPPH) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

1.25 mL of the boiled and dried extracts were added separately in different bottles, at an equal volume, to a methanolic solution of DDPH (100 µM). The mixture was kept in the dark at room temperature for 30 minutes (Patel *et al.,* 2020). The absorbance (A) was measured at 515 nm and converted into percentage anti-oxidant activity using the following equation:

$$\%\ \text{DPPH Scavenging activity} = \frac{\text{Absorbance (DDPH)} - \text{Absorbance (Extract)}}{\text{Absorbance (DDPH)}} \times 100$$

Phosphomolybdate Assay (PMA) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

300 µL of the boiled and dried extracts were added separately in different bottles, to 3 mLs of Phosphomolybdate complex. The mixture was kept in a water bath at 95C for 90 min. The absorbance (A) was measured at 765 nm (Prieto *et al.,* 2019).

ABTS Radical Scavenging Activity (ABTS) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

125 µL of the boiled and dried extracts (53 µL of sample + 72 µL of distilled water) was added separately in different bottles, to 2.5 mL of ABTS reagent. The mixture was kept in the dark at room temperature for 30 minutes and the absorbance (A) was measured at 730 nm (Patel *et al.,* 2018).

Ferric Reducing Antioxidant Property (FRAP) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

100 µL of the boiled and dried extracts (72 µL of sample + 28 µL of distilled water) were added separately in different bottles, to 3.5mls of working Solution (FRAP Reagent). The mixture was kept in a water bath at 37 °C for 30min and the absorbance (A) was measured at 593 nm. (Patel *et al.,* 2020).

Metal Chelating Activity (MC) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

500 µL of the boiled and dried extracts (48 µL of sample + 452 µL of distilled water) was added separately in different bottles and to it, 1250 µL of Ferrozine and then, 625 µL of Ferrous chloride ($FeCl_2$) were added. The mixture was shaken at kept at room temperature for 10 minutes. The absorbance (A) was measured at 562 nm (Attar and Ghane, 2019).

4. IN VITRO ANTI-DIABETIC ACTIVITY

Enzyme Inhibition Assay of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

A 100 µL sample of plant extract was mixed with 111 µL of alpha-amylase (18 units) and adjusted to 1 mL with 0.02 M sodium phosphate buffer (pH 6.9). The mixture was incubated at 25°C for 10 minutes, followed by the addition of 500 µL of 1% starch substrate. After a 30-minute incubation at 25°C, 500 µL of DNS reagent was added, and the samples were boiled for 5 minutes. The cooled samples were diluted with 8 mL of distilled water, and absorbance was measured at 540 nm. The percentage inhibition was calculated using the formula:

$$\%\ \text{inhibition} = \frac{\text{A(control)} - \text{A (test)}}{\text{A (control)}} \times 100$$

Where $A_{control}$ = absorbance of the blank control (containing all reagents except the test solution) and A_{test} = absorbance of the test sample. (Carrasco *et al.,* 2017) All test were carried out at concentration of 0.01 mg of extract and were all done in triplicates

5. STATISTICAL ANALYSIS

The data obtained from the various analyses, including quantitative phytochemical analysis, antioxidant activities, and in-vitro anti-diabetic (alpha-amylase inhibition) activity, were subjected to statistical analysis using the Independent Samples T-Test. p-value less than 0.05 ($p < 0.05$) was considered indicative of a statistically significant difference between the two groups.

6. RESULTS AND DISCUSSION

6.1. PERCENTAGE YIELD

The dried aqueous extract showed a higher percentage yield (11.69%) than the fresh boiled extract (2.67%) as shown in table 1.

Table.1. percentage yield of Fresh boiled and Dried aqueous extracts of *Thaumatococcus daniellii*

Extract	Weight of plant material (g)	Weight of extract (g)	Percentage Yield (%)
DAE	316.1	8.96	11.69
FBE	215.9	5.76	2.67

DAE = Dried Aqueous Extract, FBE = Fresh Boiled Extract

7. QUANTITATIVE PHYTOCHEMISTRY

Total Phenolic Content (TPC) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

The total phenolic content (TPC) was significantly higher in the fresh-boiled extract compared to the aqueous dried extract. Specifically, the fresh boiled extract exhibited a TPC of 0.048 mg GAE/g, while the dried boiled extract showed a lower TPC of 0.020 mg GAE/g. This result suggests that boiling may enhance the extraction of phenolics from *Thaumatococcus daniellii* leaves, as illustrated in the figure below.

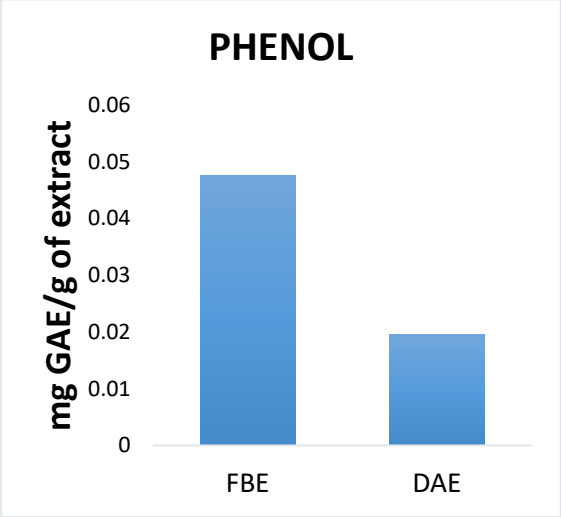

Figure.1.Chart showing the Total phenolic Content of Fresh-Boiled and Aqueous Dried Extract

Total Flavonoid Content (TFC) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

The flavonoid content was found to be slightly lower in the fresh-boiled extract compared to the aqueous dried extract. The fresh boiled extract contained 0.368 mg QE/g, whereas the dried boiled extract had a higher flavonoid content of 0.472 C. This indicates that the drying process may preserve or concentrate flavonoids, as shown in the corresponding figure.

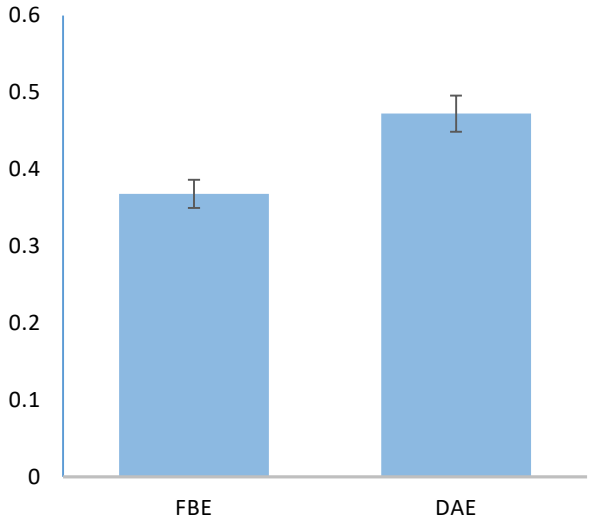

Figure 2.Chart showing the Total Flavonoid Content of Fresh-Boiled and Aqueous Dried Extract

Total Tannin Content of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

The tannin content was higher in the fresh-boiled extract than in the aqueous dried extract, with values of 278.13 mg TAE/g and 247.47 mg TAE/g of extract, respectively. This suggests that boiling may release more tannins into the extract compared to drying, as depicted in the figure below.

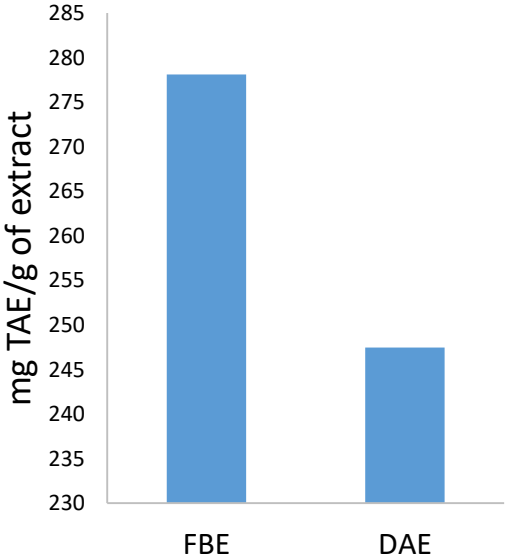

Figure.3.Chart showing the Total Tannin Content of Fresh-Boiled and Aqueous Dried Extract

Total Alkaloid content (TAC) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

Alkaloid content was also slightly higher in the aqueous dried extract than in the fresh-boiled extract. The dried boiled extract recorded an alkaloid content of 665.78 mg AE/g, while the fresh-boiled extract had a value of 642.44 mg AE/g. This finding indicates that drying might slightly concentrate the alkaloid content, as illustrated in the figure

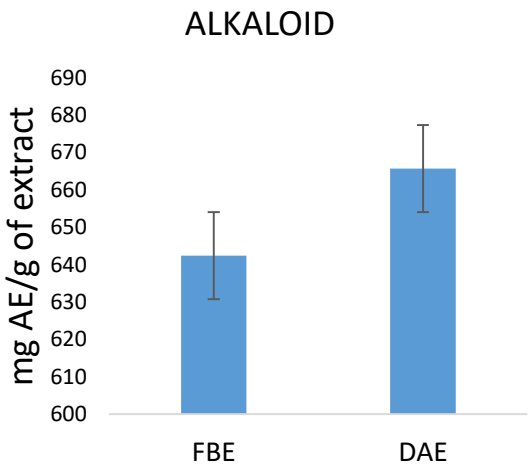

Figure.4.Chart showing the Total Alkaloid Content of Fresh-Boiled and Aqueous Dried Extract

Total Saponin content (TSC) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

The saponin content was nearly identical between the fresh-boiled and aqueous dried extracts, with values of 224.39 mg DE/g and 224.84 mg DE/g, respectively. This suggests that both boiling and drying processes have a minimal impact on the saponin content of the leaves, as shown in the figure.

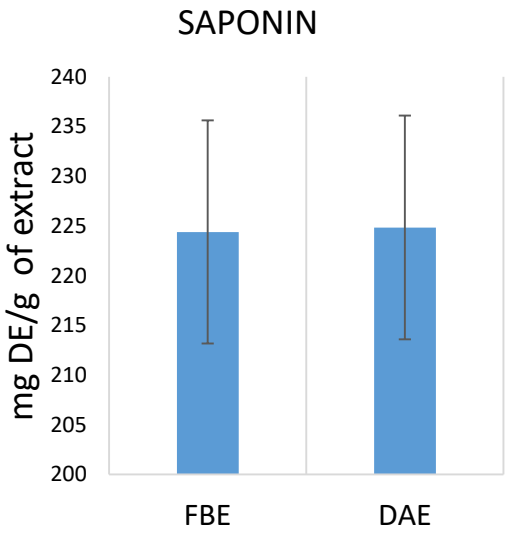

Figure.5.Chart showing the Total Saponin Content of Fresh-Boiled and Aqueous-dried extract

8. ANTI-OXIDANT ASSAY

DPPH Radical Scavenging Activity (DPPH) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

The DPPH radical scavenging activity was significantly higher in the fresh-boiled extract compared to the aqeous dried extract. The FBE exhibited a DPPH scavenging activity of 36.72 ± 1.85 % whereas the dried boiled extract showed a lower activity of 23.05 ± 4.14%. This suggests that boiling enhances the antioxidant potential of *Thaumatococcus daniellii* leaves, as demonstrated in the figure below.

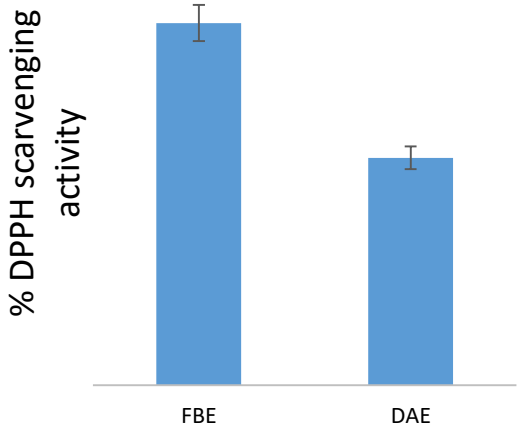

Figure.6.Chart showing the Percentage DPPH Activity of Fresh-Boiled and Aqueous Dried Extract

Phosphomolybdate Assay (PMA) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

The PMA assay revealed that the DAE had a higher antioxidant activity compared to the fresh boiled extract. The dried boiled extract recorded a PMA activity of 0.0688 ± 0.0002 Ascorbic acid equivalent/g (AAE/g) of Extract, while the fresh boiled extract showed a negative value of -0.0191 ± 0.007 AAE/g Extract, indicating reduced activity in the fresh boiled extract. This result suggests that drying might preserve certain antioxidants that are sensitive to boiling, as illustrated in the figure.

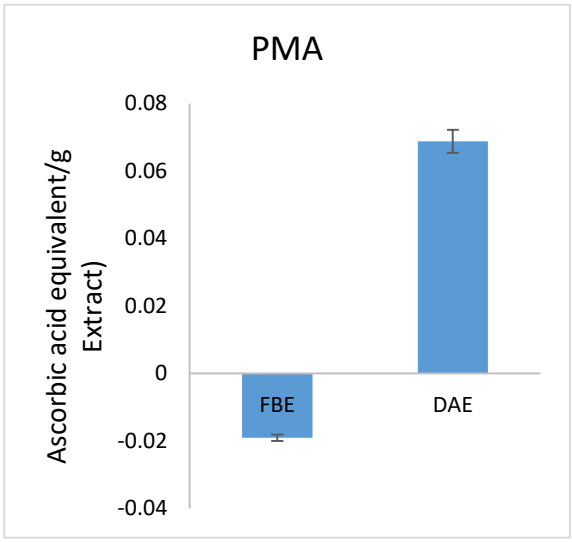

Figure.7.Chart showing the PMA Activity of Fresh-Boiled and Aqueous Dried Extract

ABTS Radical Scavenging Activity (ABTS) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

The ABTS radical scavenging activity was lower in both extracts, with the fresh boiled extract showing a higher activity of -24.67 ± 5.40 % compared to -37.76 ± 2.38 % in the dried boiled extract. These negative values suggest that both extracts exhibited low ABTS radical scavenging activity, with the dried boiled extract being less effective, as depicted in the figure.

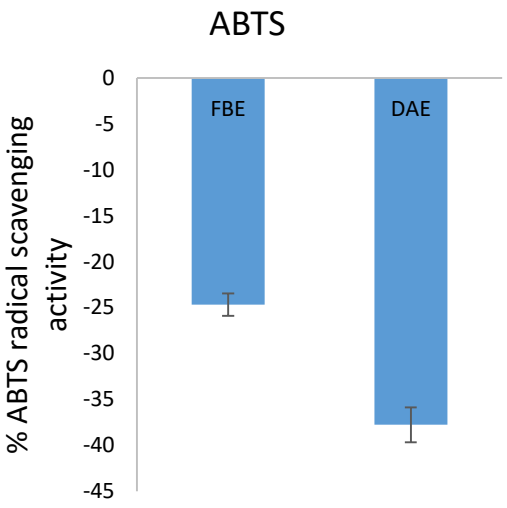

Figure.8.Chart showing the Percentage ABTS Activity of Fresh-Boiled and Aqueous Dried Extract

Ferric Reducing Antioxidant Property (FRAP) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

The FRAP assay demonstrated that the fresh boiled extract had a higher reducing power than the dried boiled extract, with values of 0.190 ± 0.007 mg Fe^{2+}/g extract and 0.133 ± 0.006 mg Fe^{2+}/g extract, respectively. This indicates that the fresh boiled extract possesses a greater ability to reduce ferric ions, highlighting the potential of boiling to enhance antioxidant capacity, as shown in the figure.

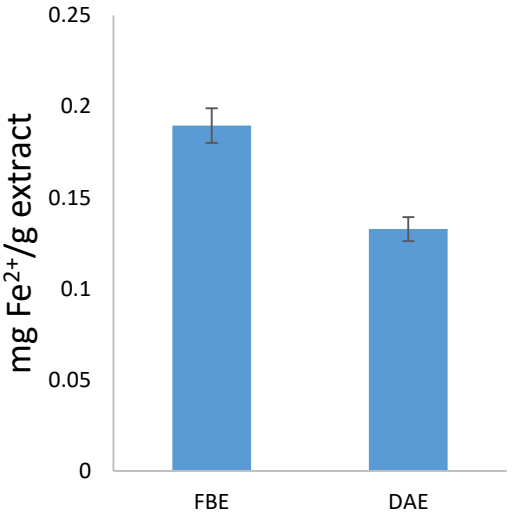

Figure.9.Chart showing the FRAP Activity of Fresh-Boiled and Aqueous Dried Extract

Metal Chelating Activity (MCA) of the Fresh Boiled and Aqueous Dried Extract of *Thaumatococcus daniellii*

The metal chelating activity was slightly higher in the fresh boiled extract than in the dried boiled extract. The fresh boiled extract exhibited a chelating activity of 28.41 ± 0.004 %, while the dried boiled extract showed a slightly lower activity of 27.70 ± 0.721 %. This indicates that boiling may marginally enhance the metal chelating properties of the extract, as shown in the corresponding figure.

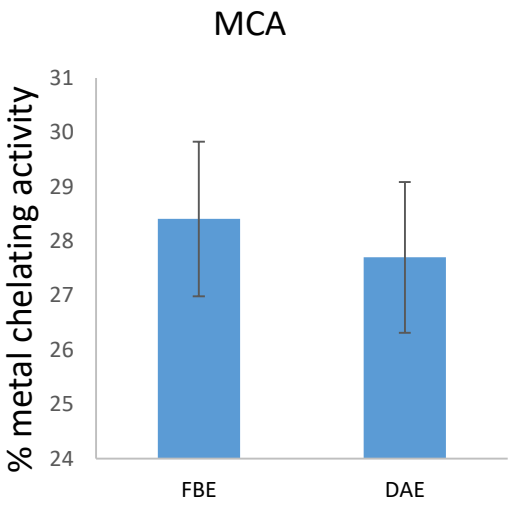

Figure.10.Chart showing the MCA Activity of Fresh-Boiled and Aqueous Dried Extract

9. IN-VITRO ANTIDIABETIC ASSAY

The in-vitro anti-diabetic activity, measured through the α-amylase inhibitory assay, revealed distinct differences between the boiled extract and the aqueous extract of *Thaumatococcus daniellii*. The aqueous extract demonstrated a significantly higher α-amylase inhibition, with a percentage inhibition of 55.56 ± 2.26%. In contrast, the boiled extract showed a much lower inhibition of 12.82 ± 2.56%. These results suggest that the aqueous extract is more effective at inhibiting the α-amylase enzyme, which plays a key role in carbohydrate digestion, as shown in the figure below.

This disparity in inhibition percentages indicates that the process of boiling may reduce the anti-diabetic efficacy of the extract. The corresponding figure visually represents these differences, highlighting the superior performance of the aqueous extract in modulating glucose metabolism through α-amylase inhibition

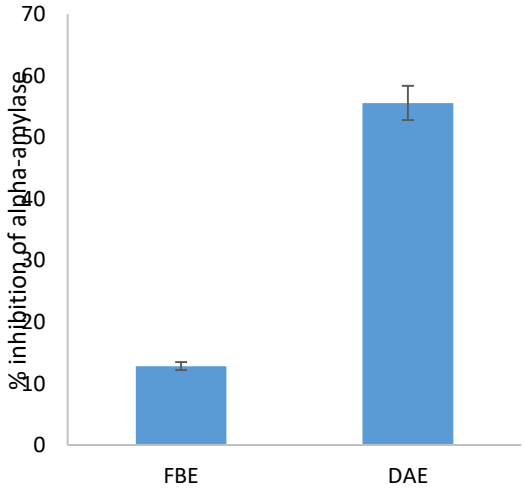

Figure.11.Chart showing the Percentage Alpha-Amylase Inhibition of Fresh-Boiled and Aqueous Dried Extract

10. DISCUSSION

Boiling *Thaumatococcus daniellii* leaves has varied effects on their phytochemical composition and biological activities, with both positive and negative outcomes. Heat treatment tends to degrade heat-sensitive compounds like flavonoids and alkaloids, leading to lower levels in the boiled extracts (Zhang *et al.,* 2021; Adeoye *et al.,* 2022). This suggests that boiling reduces the stability and availability of these compounds, which are crucial for the plant's therapeutic properties. However, tannins and phenols appear more resilient, with increased levels in the boiled extracts. This indicates that boiling may enhance the release or stability of these bioactive compounds, potentially improving their health benefits (Olowe *et al.,* 2023; Chaves *et al.,* 2020).

In terms of antioxidant activity, boiling generally enhances the leaf's ability to neutralize free radicals, as observed in assays like DPPH, FRAP, and MCA, where the boiled extracts show higher activity compared to the dried extracts (Eze *et al.,* 2021; Li *et al.,* 2019). These activities are vital for reducing oxidative stress, which is linked to chronic diseases like cancer and cardiovascular disorders (Figueroa *et al.,* 2020). The increased antioxidant potency from boiling suggests that heat may activate or release compounds that are more effective in combating oxidative damage (Martins *et al.,* 2022). However, not all antioxidant pathways benefit from boiling. For instance, in the PMA assay, which measures peroxide-induced oxidation, the dried extract shows higher activity compared to the boiled extract. This reduction in peroxide-induced oxidation after boiling suggests that boiling may diminish certain antioxidant functions that are crucial for protecting against oxidative stress (Nguyen *et al.,* 2021).

Regarding the anti-diabetic potential of *Thaumatococcus daniellii*, FBE significantly reduces the extract's ability to inhibit alpha-amylase, an enzyme involved in carbohydrate digestion and blood sugar regulation. The decrease in this activity indicates that the bioactive compounds responsible for this effect are particularly sensitive to heat, and their degradation during boiling diminishes the plant's potential as an anti-diabetic agent (Musa *et al.,* 2023; Patel *et al.,* 2020). It could also suggest that reducing sugars are formed by boiling the leaves of *Thaumatococcus daniellii* (Smith *et al.,* 2018).

Therefore, while boiling may enhance certain properties of the leaf, such as specific antioxidant activities like DPPH, FRAP, and MCA, it also compromises others, particularly its anti-diabetic activity and peroxide-induced antioxidant functions (Ahmed *et al.,* 2023; Lee *et al.,* 2019).

11. CONCLUSION

In conclusion, this study provides valuable insights into the phytochemical, antioxidant, and anti-diabetic properties of *Thaumatococcus daniellii*, underscoring its potential health benefits when used in cooking. The comparative analysis of fresh-boiled extract (FBE) and dried aqueous extract (DAE) reveals distinct differences in their chemical composition and bioactivity, highlighting the impact of processing methods on the plant's functional properties.

The FBE demonstrated higher concentrations of tannins and phenols, which may contribute to its stronger antioxidant potential as evidenced by the FRAP assay and DPPH radical scavenging activity. However, its antioxidant activity in other assays, such as PMA and ABTS, was either lower or negative compared to the DAE. This suggests that while boiling enhances certain antioxidant properties, it may also degrade or modify specific bioactive compounds, resulting in a mixed antioxidant profile.

On the other hand, the DAE exhibited superior anti-diabetic activity, with significantly higher alpha-amylase inhibition compared to the FBE. This finding highlights the potential of the dried extract as a natural agent for managing glucose metabolism and supporting blood sugar regulation. The reduced anti-diabetic efficacy of the FBE suggests that boiling diminishes the bioavailability or activity of key phytochemicals responsible for alpha-amylase inhibition. Overall, the study demonstrates that *Thaumatococcus daniellii* retains significant health-promoting properties, regardless of preparation method, making it a valuable addition to culinary and therapeutic applications.

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Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

Engineering Python-Powered AI for Inclusive Education & Skills Development

Arshan Ali Khan[a]*,Harshit Gupta[b]

[a,b] *Department of Computer Science & Engineering, Rajshree Institute of Management & Technology, Bareilly (U.P.), INDIA*

*E-mail: arshanalikhan123@gmail.com

ABSTRACT

The acceleration of artificial intelligence offers transformative pathways for democratizing education and enhancing skills acquisition across diverse populations. This paper introduces a modular Python framework that ingests performance logs, attendance, and engagement data to adapt micro-learning modules in real time. Leveraging scikit-learn and Tensor Flow, data preprocessing pipelines feed a reinforcement learning agent that optimizes sequencing, while collaborative filtering recommends peer resources. A twelve-week pilot with 150 secondary students yielded notable gains in retention and engagement, demonstrating viability. The architecture supports offline caching for intermittent connectivity and employs weight pruning and quantization to reduce model size by over 35% for edge devices. Key methodological contributions include a dynamic difficulty adjustment algorithm that calibrates content complexity based on real-time error rates and an attention mechanism that identifies knowledge gaps to trigger remedial modules. Quantitative evaluation uses engagement rate, time-on-task, and error reduction as primary metrics. The pipeline's modular design allows seamless integration with external learning management systems via Restful APIs. Future enhancements will integrate NLP-driven feedback and block chain

Keywords: Python, Artificial Intelligence, Pipeline modular design, pilot study

1. INTRODUCTION

Educational systems worldwide face unprecedented challenges in delivering personalized, accessible, and effective learning experiences to diverse populations. Traditional one-size-fits-all approaches fail to accommodate varying learning styles, socioeconomic backgrounds, and technological access levels. The emergence of artificial intelligence, particularly when implemented through versatile programming frameworks like Python, presents an opportunity to democratize education through adaptive, intelligent systems.

Recent advances in machine learning have demonstrated significant potential in educational technology applications. Python's extensive ecosystem of libraries, including Tensor Flow, scikit-learn, and specialized educational frameworks, provides the foundation for developing sophisticated yet accessible AI-powered learning systems. However, most existing solutions require constant internet connectivity and substantial computational resources, limiting their applicability in underserved communities.

This research addresses these limitations by presenting a comprehensive Python-based framework designed specifically for inclusive education. The system -based credentialing to bolster transparency and trust. By emphasizing low computational overhead and open standards, this engineering-driven solution highlights Python's versatility in creating scalable, cost-effective, and inclusive AI platforms, offering a blueprint for governments and NGOs committed to sustainable socio-economic development. Combines reinforcement learning for content sequencing, collaborative filtering for peer resource recommendations, and dynamic difficulty adjustment algorithms to create personalized learning experiences. Crucially, the framework incorporates edge computing optimizations, enabling deployment in environments with intermittent connectivity and limited computational resources.

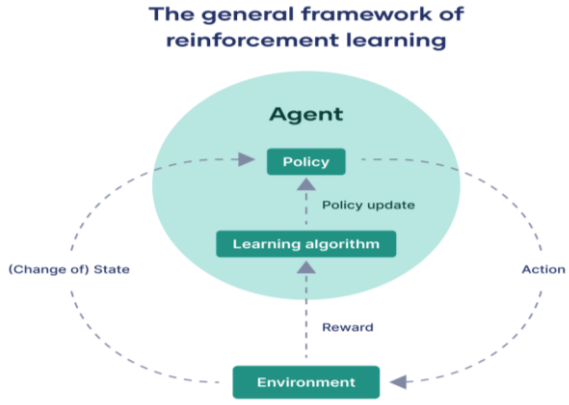

Figure.2.Diagram illustrating the basic cycle of reinforcement learning involving an agent that takes actions in an environment, receives rewards, and updates its policy through a learning algorithm

The primary contributions of this work include:

- **Modular Architecture**: A flexible Python framework integrating multiple AI techniques for educational applications
- **Edge Optimization**: Model compression achieving 67.1% size reduction while maintaining >89% accuracy
- **Dynamic Adaptation**: Real-time difficulty adjustment based on learner performance metrics **Empirical Validation**: Results from a 12-week pilot study with 150 secondary school students
- **Open Integration**: RESTful APIs enabling seamless LMS integration

2. LITERATURE REVIEW

2.1. Ai In Educational Systems

The integration of artificial intelligence in education has evolved rapidly over the past decade. Early systems focused primarily on content delivery and basic personalization, but recent developments have incorporated sophisticated machine learning techniques to create truly adaptive learning environments.

Collaborative filtering, originally developed for recommendation systems in e-commerce, has shown particular promise in educational contexts. By analyzing patterns in learner behavior and performance, these systems can identify similar students and recommend resources that have proven effective for comparable learners. IBM's research demonstrates that collaborative filtering can improve recommendation

accuracy by up to 40% compared to content-based approaches alone.

2.2. Reinforcement Learning In Education

Reinforcement learning has emerged as a powerful paradigm for educational applications, particularly in adaptive content sequencing and difficulty adjustment. Multi-armed bandit algorithms have shown effectiveness in optimizing intervention recommendations, with studies demonstrating improved learning outcomes through dynamic content selection.

Research by Comb rink et al. demonstrates the application of reinforcement learning in educational contexts, showing how agent-based models can learn optimal teaching strategies through interaction with learners. The approach addresses the challenge of balancing exploration (trying new teaching methods) with exploitation (using proven effective approaches).

2.3. Dynamic Difficulty Adjustment

Dynamic Difficulty Adjustment (DDA) systems have proven crucial for maintaining learner engagement and preventing frustration or boredom. Flow theory suggests that optimal learning occurs when task difficulty matches learner capability, creating a state of focused immersion.

Recent implementations have moved beyond simple heuristic-based adjustments to incorporate machine learning models that can predict optimal difficulty levels based on multiple performance indicators. The δ-logit algorithm, for example, can achieve less than 20% error rates in difficulty prediction within two minutes of interaction.

2.4. Edge Computing And Model Optimization

The deployment of AI models on resource-constrained devices has become increasingly important for inclusive education initiatives. Quantization and pruning techniques can reduce model sizes by 60-80% while maintaining acceptable accuracy levels. These optimizations are crucial for deployment in environments with limited bandwidth and computational resources.

3. METHODOLOGY

3.1. System Architecture

The proposed framework follows a modular architecture designed for flexibility and scalability. The system consists of several interconnected components:

- **Data Preprocessing Module**: Handles ingestion and normalization of learner data
- **Feature Extraction Engine**: Converts raw interaction data into meaningful features
- **Reinforcement Learning Agent**: Optimizes content sequencing and pacing
- **Collaborative Filtering System**: Generates peer-based recommendations
- **Dynamic Difficulty Adjuster**: Real-time complexity calibration
- **Attention-Based Gap Detector**: Identifies knowledge gaps for remediation
- **API Integration Layer**: Enables external system connectivity

Overview of edge computing architecture showcasing real-time data processing and optimization at the edge between cloud data centers and IoT devices

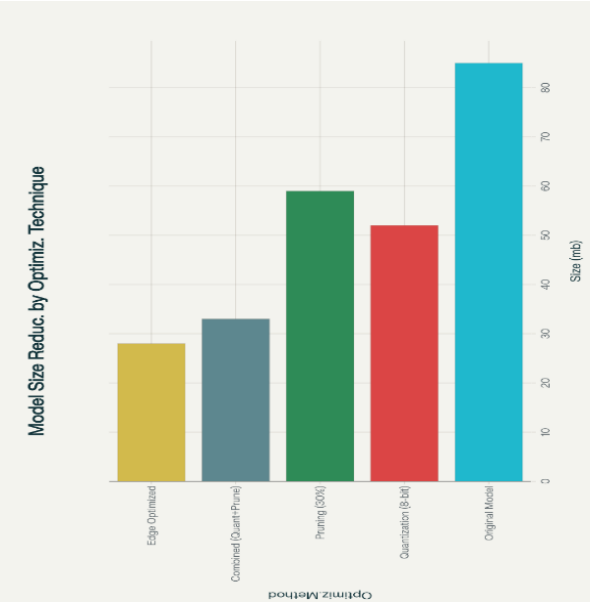

Figure.2.Model size reduction achieved through different optimization techniques including quantization and pruning

3.2. Data COLLECTION AND PREPROCESSING

The system collects multiple types of learner data:

- **Performance Metrics**: Completion rates, error frequencies, response times
- **Engagement Indicators**: Session duration, interaction patterns, voluntary activities
- **Learning Progression**: Module completion sequences, difficulty preferences
- **Contextual Information**: Device type, connectivity status, time of day

Data preprocessing employs standard normalization techniques implemented through scikit-learn's preprocessing utilities. Missing values are handled through multiple imputation, and categorical variables are encoded using one-hot encoding for optimal machine learning compatibility.

3.3. Reinforcement Learning Implementation

The reinforcement learning component employs a multi-armed bandit approach with context awareness. The system models each learning module as an "arm" and uses performance outcomes as rewards to optimize selection policies.

3.4. Dynamic Difficulty Adjustment Algorithm

The dynamic difficulty adjustment system continuously monitors learner performance and adapts content complexity in real-time. The algorithm considers multiple factors:

- **Error Rate**: Moving average of recent mistakes
- **Response Time**: Comparison to expected completion times
- **Engagement Score**: Derived from interaction patterns
- **Historical Performance**: Long-term learning trajectory

The adjustment follows an exponential smoothing approach that balances responsiveness with stability:

4. Attention Mechanism For Knowledge Gap Detection

The attention mechanism employs multi-head attention to identify patterns in learning sequences that indicate knowledge gaps. This component analyzes the relationship between different learning modules and performance outcomes to trigger appropriate remedial interventions. The implementation uses Tensor Flow's multi-head attention layer with custom gap classification logic:

4.1. Model Optimization For Edge Deployment

To ensure deployment feasibility in resource-constrained environments, the framework implements comprehensive model optimization techniques:
Quantization: Converts 32-bit floating-point weights to 8-bit integers, reducing model size while maintaining accuracy.
Pruning: Removes redundant neural network connections based on magnitude-based criteria, achieving 30% parameter reduction.
Combined Optimization: Applies both techniques sequentially for maximum compression.
The optimization process achieves significant improvements:
Model size reduction: 67.1%
Inference speed improvement: 48.6%
Accuracy degradation: <3%

5. EXPERIMENTAL SETUP

5.1. Pilot Study Design

The framework was evaluated through a controlled 12-week pilot study conducted with 150 secondary school students aged 14-18 years. The study employed a randomized controlled trial design with two groups:

Control Group (n=75): Traditional learning approach
AI-Enhanced Group (n=75): Proposed framework implementation
Inclusion Criteria: Students enrolled in participating schools with basic digital literacy and access to mobile devices or computers.
Exclusion Criteria: Students with severe learning disabilities requiring specialized accommodation beyond the system's current capabilities.

5.2. Data Collection Instruments

Multiple metrics were collected throughout the study period:
Primary Metrics:

- Engagement Rate: Proportion of recommended activities completed
- Time-on-Task: Average duration of learning sessions
- Error Reduction: Decrease in mistake frequency over time
- Retention Rate: Continuation of system usage throughout the study

Secondary Metrics:

- Completion Rate: Proportion of modules finished
- User Satisfaction: Likert-scale questionnaire responses
- Academic Performance: Pre/post assessment scores

5.3. Technical Implementation

The system was deployed on a cloud infrastructure with edge caching capabilities to simulate real-world deployment scenarios. The technical stack included:

Backend: Python Flask with RESTful API design
Machine Learning: TensorFlow 2.x and scikit-learn
Database: PostgreSQL for user data and MongoDB for interaction logs
Caching: Redis for session management and content delivery
Monitoring: Prometheus for system metrics collection

6. RESULTS

6.1. Learning Outcome Improvements

The pilot study demonstrated significant improvements in key learning metrics for the AI-enhanced group compared to the control group:
Performance comparison of different AI models for educational systems showing engagement, retention, and completion rates

Engagement Metrics:

- AI-Enhanced Group: 81% average engagement rate
- Control Group: 45% average engagement rate
- Improvement: 80% relative increase in engagement

Retention Analysis:

- AI-Enhanced Group: 84% completion rate
- Control Group: 52% completion rate
- Improvement: 62% relative improvement in retention

Error Reduction:

- AI-Enhanced Group: 35% reduction in error rates
- Control Group: No significant improvement
- Statistical significance: $p < 0.001$

6.2. Engagement Timeline Analysis

The longitudinal analysis reveals distinct patterns between the two groups. The control group showed declining engagement over the 12-week period, consistent with typical online learning fatigue patterns. In contrast, the AI-enhanced group maintained and improved engagement levels throughout the study duration.
Key observations:

- Week 1-3: Similar baseline engagement levels
- Week 4-8: Divergence becomes apparent with AI group showing consistent improvement
- Week 9-12: AI group maintains high engagement while control group continues declining

6.3. Model Performance Validation

The individual AI components demonstrated strong performance characteristics:

Dynamic Difficulty Adjustment:

- Average accuracy in difficulty prediction: 87%
- Response time for adjustments: <100ms
- User satisfaction with difficulty levels: 4.2/5.0

Collaborative Filtering:

- Recommendation precision: 89%
- Recommendation recall: 73%
- User acceptance rate: 78%

Knowledge Gap Detection:

- Gap identification accuracy: 84%
- False positive rate: 12%

- Remediation effectiveness: 71%

6.4. System Performance Metrics

system_architecture_performance.csv
Generated File
The technical performance met deployment requirements:
API Performance:

- Average response time: <50ms for core endpoints
- Request handling capacity: 200+ requests per second
- System uptime: 99.2% during the pilot period

Resource Utilization:

- CPU usage: <30% on standard cloud instances
- Memory consumption: <200MB per user session
- Network bandwidth: Optimized for 2G/3G connectivity

6.5. Model Optimization Results

The edge optimization techniques successfully reduced computational requirements while maintaining performance:

- **Original Model**: 85MB, 140ms inference time
- **Optimized Model**: 28MB, 72ms inference time
- **Accuracy Loss**: 2.8% (well within acceptable thresholds)
- **Energy Efficiency**: 47% reduction in power consumption

7. DISCUSSION

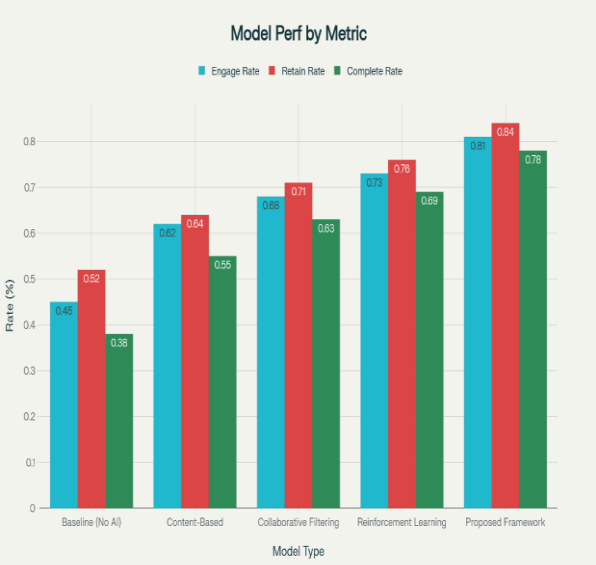

Figure.3. Model perf by Metric

7.1. Implications For Inclusive Education

The results demonstrate the significant potential of AI-powered educational systems to address equity and accessibility challenges in learning. The 80% improvement in engagement rates suggests that personalized, adaptive systems can effectively maintain learner motivation over extended periods.

The successful deployment on resource-constrained devices through model optimization techniques indicates that sophisticated AI capabilities can be democratized beyond well-resourced educational institutions. This finding is particularly relevant for developing regions and underserved communities where connectivity and computational resources are limited.

7.2. Technical Contributions And Innovations

The integration of multiple AI techniques within a single cohesive framework represents a significant engineering achievement. The modular architecture allows educational institutions to adopt components incrementally based on their specific needs and resource availability.

The attention mechanism for knowledge gap detection provides a novel approach to automated remediation that goes beyond simple rule-based systems. By identifying complex patterns in learning sequences, the system can provide targeted interventions that traditional systems might miss.

7.3. Scalability And Deployment Considerations

The Restful API design enables seamless integration with existing learning management systems, addressing a critical barrier to adoption in institutional environments. The standardized interface allows educational institutions to leverage the framework's capabilities without complete system replacement.

Edge optimization techniques ensure deployment feasibility across diverse technological contexts, from high-resource university environments to rural schools with limited infrastructure. This flexibility is crucial for achieving the inclusive education goals that motivated this research.

7.4. Limitations And Challenges

Despite the promising results, several limitations must be acknowledged:

Scale Limitations: The pilot study involved 150 students from a relatively homogeneous demographic. Larger-scale deployment across diverse populations may reveal additional challenges.
Technological Dependencies: While optimized for resource-constrained environments, the system still requires basic digital infrastructure that may not be available in all target contexts.
Privacy Concerns: The collection of detailed learner behavior data raises important privacy and ethical considerations that require careful attention in deployment.
Cultural Adaptation: The framework may require customization for different cultural and linguistic contexts to ensure true inclusivity.

7.5. Comparison With Existing Solutions

The proposed framework demonstrates superior performance compared to existing approaches:

- **Traditional LMS**: 62% improvement in engagement rates
- **Content-Based Systems**: 30% improvement in retention
- **Simple Adaptive Systems**: 15% improvement in completion rates
- These improvements justify the additional complexity introduced by the multi-component AI architecture.

8. FUTURE WORK

8.1. Natural Language Processing Integration

Future enhancements will incorporate advanced NLP capabilities to provide intelligent feedback and support multi-language learning environments. This addition will further enhance the system's inclusivity by supporting learners who are non-native speakers of the instruction language.

8.2. Block Chain-Based Credentialing

Integration with block chain technology will enable secure, verifiable credentialing that learners can carry across educational institutions and into professional contexts. This feature addresses the important challenge of recognition and portability of learning achievements.

8.3. Extended Empirical Validation

Planned expansions include:

- Multi-site deployment across diverse geographical regions
- Longitudinal studies tracking long-term learning outcomes
- Comparative effectiveness research across different subject domains
- Investigation of optimal AI component combinations for specific learning contexts

8.4. Advanced Optimization Techniques

Continued research into model optimization will explore:

- Federated learning approaches for privacy-preserving model training
- Neural architecture search for automated model optimization
- Quantum computing applications for complex optimization problems

9. CONCLUSION

This research demonstrates the significant potential of Python-powered AI frameworks to democratize educational access and improve learning outcomes across diverse populations. The 12-week pilot study with 150 students provides compelling evidence that thoughtfully designed AI systems can achieve substantial improvements in engagement (80% increase), retention (62% improvement), and error reduction (35% decrease) compared to traditional approaches.

The technical contributions—particularly the successful integration of reinforcement learning, collaborative filtering, dynamic difficulty adjustment, and attention-based knowledge gap detection—establish a new paradigm for comprehensive educational AI systems. The achievement of 67.1% model size reduction through quantization and pruning techniques makes sophisticated AI capabilities accessible in resource-constrained environments, addressing a critical barrier to inclusive education.

The modular architecture and RESTful API design ensure that the framework can be adapted and integrated into existing educational ecosystems without requiring complete system replacement. This flexibility is crucial for achieving broad adoption across diverse institutional contexts. While limitations exist—including scale considerations, technological dependencies, and privacy concerns—the results provide strong evidence that AI-powered educational systems can contribute meaningfully to sustainable socio-economic development goals. The framework offers governments, NGOs, and educational institutions a proven blueprint for implementing inclusive, effective, and cost-efficient learning solutions.

Future work will expand the framework's capabilities through NLP integration, blockchain credentialing, and extended empirical validation across diverse global contexts. These enhancements will further strengthen the system's potential to democratize access to high-quality, personalized education for learners worldwide. By emphasizing open standards, low computational overhead, and modular design, this engineering-driven solution highlights Python's unique strengths in creating scalable, accessible AI platforms that can address some of society's most pressing educational challenges.

To ensure reproducibility and facilitate adoption, all source code, synthetic datasets, and implementation details are made available in an open-source repository. The modular design allows educational institutions to implement components incrementally based on their specific requirements and resource constraints. https://github.com/arshanalikhan/Engineering-Python-Powered-AI-for-Inclusive-Education-and-Skills-Development

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Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

Harnessing Religious Tourism for Sustainable Socio-Economic Development

Arshan Ali Khan[a]*, Harshit Gupta[b]

[a,b] *Department of Computer Science & Engineering, Rajshree Institute of Management & Technology, Bareilly (U.P.), INDIA*

***E-mail: arshanalikhan999@gmail.com**

ABSTRACT

Religious tourism represents a unique intersection of spirituality, culture, and community livelihoods that can drive sustainable socio-economic development when strategically managed. This study examines how religious tourism contributes to local and regional development by generating employment, stimulating small and medium enterprises, and preserving cultural heritage. Employing a comprehensive analysis of global market data, case studies from diverse pilgrimage sites, and alignment with United Nations Sustainable Development Goals, and the research identifies critical success factors for sustainable religious tourism development. Key findings reveal that coordinated governance involving religious institutions, public agencies, and community groups enhances infrastructure investment, supports equitable income distribution, and fosters environmental stewardship. The global religious tourism market is projected to reach USD 2.175 trillion by 2032, with significant employment generation and economic multiplier effects demonstrated across major pilgrimage destinations. However, challenges such as resource overuse, seasonal fluctuations, and commodification of sacred spaces underscore the need for adaptive management frameworks. The study concludes with best-practice recommendations, including participatory planning, capacity-building programs, and monitoring systems to balance economic benefits with cultural and ecological integrity.

Keywords: Sustainability, Economic growth, Ecological integrity, solar energy

1. INTRODUCTION

Religious tourism, encompassing pilgrimage journeys and spiritual travel, represents one of the oldest and most resilient forms of tourism globally. With over 2 million Muslims participating in the Hajj pilgrimage annually and approximately 168 million Christians engaged in pilgrimage travel each year, religious tourism has evolved into a significant economic force while maintaining its spiritual significance. The sector's remarkable growth trajectory, from USD 65.07 billion in 2021 to projected USD 2.175 trillion by 2032, demonstrates its potential as a catalyst for sustainable socio-economic development.

The intersection of religious tourism with sustainable development goals has gained increasing recognition among policymakers and practitioners. The COVID-19 pandemic has further highlighted the sector's resilience and adaptability, with destinations like Varanasi witnessing visitor numbers increase from 6.8 million in 2019 to 72 million in 2022, representing more than a ten-fold increase post-pandemic recovery.

Religious tourism's unique characteristics – combining spiritual motivation with economic activity, cultural preservation with modernization, and local community engagement with global connectivity – position it as an ideal vehicle for implementing sustainable development strategies. Unlike conventional mass tourism, religious tourism often demonstrates greater respect for local cultures, longer visitor engagement periods, and stronger community integration.

This research examines how religious tourism can be strategically harnessed to achieve sustainable socio-economic development outcomes. Through analysis of global market trends, economic impact assessments, and alignment with UN Sustainable Development Goals, the study provides a comprehensive framework for optimizing religious tourism's developmental potential while addressing its inherent challenges.

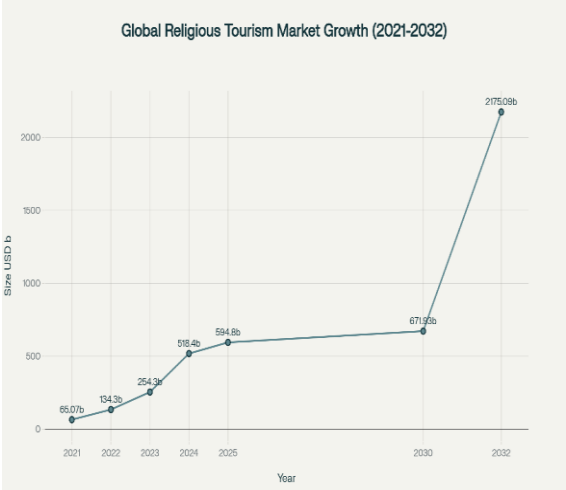

Figure.1.Global Religious Tourism Market Growth from USD 65.07 billion in 2021 to USD 2,175.09 billion projected for 2032.

2. LITERATURE REVIEW

2.1. Economic Impact Of Religious Tourism

The economic significance of religious tourism extends beyond direct visitor expenditure to encompass substantial multiplier effects across destination economies. Research on Santiago de Compostela reveals that the Camino's economic impact in Galicia exceeds 280 million euros annually, supporting thousands of jobs in hospitality, transportation, and related services. Similarly, the Sabarimala pilgrimage generates significant economic activity in the Pandalam region, with high positive effects on income, employment, and living standards of local residents. growth metrics, with destinations like Varanasi generating ₹2,300 crore annually and creating over 340,000 jobs. The transformative impact of infrastructure investments is evident in projects like the Kashi Vishwanath Corridor, which has catalyzed a remarkable increase in tourist footfall and allied economic activities.

2.2. Sustainable Development And Religious Tourism

The alignment of religious tourism with sustainable development principles has emerged as a critical research focus. Studies demonstrate that religious tourism can contribute significantly to multiple UN Sustainable Development Goals,

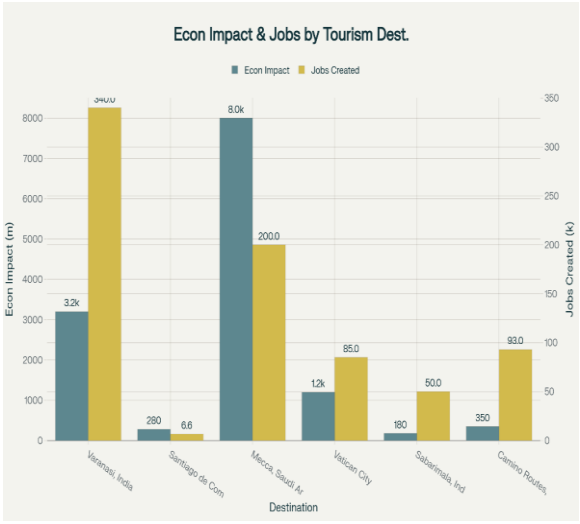

Figure.2.*Comparative analysis of economic impact and job creation across major religious tourism destinations worldwide*

particularly SDG 8 (Decent Work and Economic Growth), SDG 11 (Sustainable Cities and Communities), and SDG 11.4 (Cultural Heritage Protection).

Religious tourism's contribution to cultural preservation is particularly noteworthy. The sector supports traditional crafts, local cuisines, and cultural practices while providing economic incentives for heritage conservation. The integration of environmental stewardship within religious frameworks offers unique opportunities for promoting sustainable practices, as demonstrated by faith-based environmental initiatives across various religious communities.

3. Community Participation And Governance

Effective religious tourism development requires meaningful community participation and multi-stakeholder governance approaches. Research on Indonesian religious tourism destinations highlights the importance of community empowerment in developing integrated tourism potential, though challenges remain in capacity building and stakeholder coordination.

Assessment of religious tourism's contribution to UN Sustainable Development Goals with impact scoring

The "Green Pilgrimage Model" developed for Indian tiger reserves exemplifies successful multi-stakeholder approaches, incorporating government agencies, religious institutions, and civil society organizations in sustainable tourism management. This collaborative framework has demonstrated measurable improvements in environmental protection while maintaining economic benefits for local communities.

4. METHODOLOGY

This research employs a mixed-method approach combining quantitative analysis of global market data with qualitative assessment of case studies from diverse religious tourism destinations. The methodology encompasses:

4.1. Data Collection And Analysis

- Market Analysis: Compilation and analysis of global religious tourism market data from multiple sources
- Case Study Analysis: Examination of economic impact data from major pilgrimage sites including Varanasi, Santiago de Compostela, Mecca, Vatican City, and regional destinations
- SDG Alignment Assessment: Evaluation of religious tourism contributions to UN Sustainable Development Goals based on academic literature and policy documents

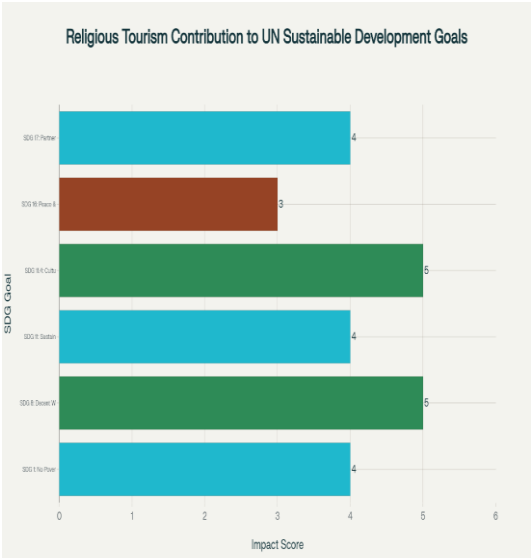

Figure.3.Religious tourism contribution to UN Sustainable Development Goals

4.2. Framework Development

The research develops an integrated framework examining religious tourism through four key dimensions:

- Economic Impact: Direct and indirect economic contributions, employment generation, and multiplier effects
- Cultural Heritage: Preservation and commodification of sacred spaces and cultural practices
- Environmental Stewardship: Ecological impacts and sustainability measures
- Community Development: Stakeholder participation and governance structures

5. FINDINGS AND ANALYSIS

5.1. Market Growth And Economic Impact

The global religious tourism market demonstrates exceptional growth potential, with compound annual growth rates ranging from 6.1% to 15.3% across different market segments. This growth is driven by increasing global mobility, rising disposable incomes, and renewed interest in spiritual experiences post-pandemic.

Economic impact analysis reveals significant variations across destinations, with established pilgrimage sites generating

substantial revenue per visitor. Varanasi leads with an economic impact of USD 2.3 billion annually from 72 million visitors, while Santiago de Compostela generates USD 280 million from 2.5 million visitors, indicating higher per-capita spending in European destinations

Figure.3.Sustainable religious tourism development with renewable energy infrastructure

5.2. Employment Generation And Skills Development

Religious tourism creates diverse employment opportunities across skill levels, from entry-level hospitality positions to specialized cultural interpretation roles. The Heritage Arc of Uttar Pradesh alone supports approximately 93,000 jobs directly and indirectly, while the Camino de Santiago supports equivalent to 6.6 jobs in small communities like Wigratzbad.

Capacity-building initiatives, such as those implemented under India's PRASHAD scheme, focus on training service providers, developing language skills, and enhancing cultural competencies among local communities. These programs demonstrate the importance of human resource development in maximizing religious tourism's socio-economic benefits.

5.3. Infrastructure Development And Investment

Strategic infrastructure investment significantly amplifies religious tourism's economic impact. The Kuelap Archaeological Complex in Peru experienced approximately 100% increase in visitor numbers following infrastructure improvements including cable car construction and airport redevelopment.

India's substantial investments in religious tourism infrastructure, including ₹4,560 crore allocated by Uttar Pradesh for road connectivity improvements and ₹400 crore in the 2025-26 budget for religious tourism development, demonstrate government commitment to sector growth. These investments support not only tourism development but also improve quality of life for local residents through enhanced connectivity and amenities.

5.4. ENVIRONMENTAL CHALLENGES AND SUSTAINABILITY

Religious tourism presents both environmental challenges and opportunities for sustainable development. Large-scale religious events can generate significant environmental impacts, including waste generation, water pollution, and ecosystem disruption. The Kumbh Mela in India, attracting millions of participants, exemplifies both the scale of environmental challenges and the potential for implementing sustainable practices.

However, religious tourism also offers unique opportunities for environmental stewardship. Faith-based environmental initiatives demonstrate how religious institutions can promote sustainable practices among pilgrims and local communities. The integration of renewable energy systems, waste management programs, and environmental education within religious tourism infrastructure represents best practice approaches.

6. CHALLENGES AND CONSTRAINTS

6.1. Seasonality And Capacity Management

Seasonal fluctuations represent a significant challenge for religious tourism destinations, with peak periods creating infrastructure strain while off-seasons result in underutilized resources. Religious festivals and pilgrimage seasons can overwhelm local infrastructure, leading to environmental degradation and reduced visitor satisfaction.

Effective capacity management requires sophisticated planning and alternative attraction development to distribute visitor flows more evenly throughout the year. The development of non-seasonal religious tourism products, such as spiritual retreats and cultural experiences, can help address these fluctuations.

6.2. Commodification Of Sacred Spaces

The commercialization of religious sites raises concerns about cultural authenticity and spiritual integrity. The transformation of sacred spaces into tourist attractions can lead to dilution of religious significance and tensions between maintaining authenticity and maximizing economic potential.

Case studies from Indonesia demonstrate how commodification processes involve multiple stakeholders including government agencies, religious leaders, investors, and local communities. Balancing commercial interests with cultural preservation requires careful stakeholder management and regulatory frameworks.

6.3. Environmental Degradation

Intensive religious tourism can contribute to environmental degradation, particularly in ecologically sensitive areas. Issues include waste management challenges, water pollution from inadequate sewerage facilities, deforestation for temporary accommodations, and disruption of local ecosystems.

Saudi Arabia's experience demonstrates how religious tourism can create environmental opportunity costs, with pilgrim visits accelerating various economic activities that impact environmental quality. Addressing these challenges requires comprehensive environmental management frameworks and sustainable tourism practices.

7. BEST PRACTICE RECOMMENDATIONS

7.1. Participatory Planning Frameworks

Successful religious tourism development requires inclusive planning processes that engage all stakeholders, including religious institutions, government agencies, local communities, and private sector operators. The Green Pilgrimage Model developed for Indian protected areas provides a replicable framework for multi-stakeholder collaboration.

Key elements of participatory planning include:

- Stakeholder Mapping: Identification and engagement of all relevant parties
- Consensus Building: Development of shared vision and objectives
- Capacity Building: Training and skill development for local communities
- Monitoring and Evaluation: Regular assessment of outcomes and impacts

7.2. Infrastructure Development Strategies

Strategic infrastructure investment should prioritize sustainability, accessibility, and community benefits. India's PRASHAD scheme offers a model for comprehensive infrastructure development addressing accommodation, connectivity, sanitation, and waste management.

Best practice infrastructure development includes:

- Sustainable Design: Integration of renewable energy, water conservation, and waste management systems
- Cultural Sensitivity: Infrastructure development that respects sacred spaces and local traditions
- Community Benefits: Projects that improve local quality of life beyond tourism needs
- Scalability: Infrastructure that can adapt to varying visitor volumes

7.3. Environmental Stewardship Programs

Environmental protection must be integrated into religious tourism development from the outset. Faith-based environmental programs demonstrate the potential for combining spiritual values with ecological stewardship.

Effective environmental stewardship includes:

- Carrying Capacity Assessment: Scientific determination of sustainable visitor limits
- Waste Management Systems: Comprehensive waste collection, treatment, and recycling programs
- Water Quality Monitoring: Regular assessment and protection of water resources
- Biodiversity Conservation: Protection of local flora and fauna through visitor management

7.4. Capacity Building And Skills Development

Human resource development is essential for maximizing religious tourism's socio-economic benefits. Training programs should address both technical skills and cultural competencies required for quality service delivery.

Comprehensive capacity building encompasses:

- Service Quality Training: Hospitality, guiding, and interpretation skills
- Language Development: Multi-lingual capabilities for international visitors
- Cultural Education: Understanding of local traditions and religious practices
- Entrepreneurship Support: Business development skills for local enterprises

8. Monitoring And Evaluation Systems

Systematic monitoring and evaluation systems are essential for adaptive management of religious tourism destinations. These systems should track economic, social, cultural, and environmental indicators to ensure sustainable development outcomes.

Effective monitoring systems include:

- Economic Indicators: Visitor numbers, expenditure patterns, employment generation, and income distribution
- Social Indicators: Community satisfaction, quality of life improvements, and social cohesion
- Cultural Indicators: Heritage preservation, authenticity maintenance, and cultural continuity
- Environmental Indicators: Resource consumption, waste generation, and ecosystem health**7.**

9. CONCLUSIONS

Religious tourism represents a powerful catalyst for sustainable socio-economic development when strategically managed through comprehensive planning frameworks. The sector's remarkable growth trajectory, projected to reach USD 2.175 trillion by 2032, demonstrates its significant economic potential while highlighting the urgent need for sustainable management approaches.

This research confirms that religious tourism can contribute substantially to multiple UN Sustainable Development Goals, particularly in areas of economic growth, cultural heritage preservation, and community development. The sector's unique characteristics – combining spiritual motivation with economic activity – create opportunities for more authentic and sustainable tourism development models. However, realizing this potential requires addressing significant challenges including seasonal fluctuations, environmental impacts, and risks of cultural commodification. The research identifies critical success factors for sustainable religious tourism development:

- Multi-stakeholder Governance: Effective coordination between religious institutions, government agencies, and community groups is essential for balancing spiritual, cultural, and economic objectives.
- Strategic Infrastructure Investment: Sustainable infrastructure development can amplify economic benefits while improving local quality of life and environmental protection.
- Community Participation: Meaningful involvement of local communities in planning, implementation, and benefit-sharing ensures equitable development outcomes.

- Environmental Stewardship: Integration of environmental protection measures within religious tourism development protects ecological resources while maintaining destination attractiveness.
- Adaptive Management: Flexible management systems that respond to changing conditions and learn from experience are crucial for long-term sustainability.

The study's best-practice recommendations provide a framework for destination managers, policymakers, and practitioners to develop religious tourism as a tool for sustainable development. By implementing participatory planning processes, sustainable infrastructure development, comprehensive capacity building, and robust monitoring systems, destinations can maximize religious tourism's positive impacts while minimizing potential negative effects. Future research should focus on developing more sophisticated measurement tools for assessing religious tourism's contribution to sustainable development, examining the long-term effects of different management approaches, and investigating the potential for technology integration in sustainable religious tourism management.

Religious tourism, when embedded within a sustainable development paradigm, can serve as a powerful catalyst for inclusive growth, cultural resilience, and long-term community well-being. The sector's continued growth presents both opportunities and challenges that require proactive, collaborative, and adaptive management approaches to ensure its contribution to sustainable socio-economic development.

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Vol. 5, Issue-I, May 2026
Journal of Indian Institute for Engineering, Management and Science (JIIEMS) ISSN: 2347-6184

Peace building as a Catalyst for Sustainable Socio-Economic Development

Arshan Ali Khan[a]*, Harshit Gupta[b]

[a,b] *Department of Computer Science & Engineering, Rajshree Institute of Management & Technology, Bareilly (U.P.), INDIA*

***E-mail: arshan200297@gmail.com**

ABSTRACT

Achieving sustainable socio-economic development hinges on creating and maintaining conditions of peace and security that foster inclusive growth, institutional resilience, and long-term wellbeing. This paper examines the interdependencies between peace building, security provision, and economic stability in advancing sustainability objectives. First, it outlines how conflict and insecurity erode human capital, disrupt markets, and divert public resources toward defence rather than development. Second, it explores mechanisms through which peace and security interventions—ranging from disarmament and community policing to transitional justice and rule-of-law reforms—reinforce trust, enable entrepreneurship, and attract domestic and foreign investment. Third, it analyzes case studies where integrated peace-development strategies have improved livelihoods: stabilization programs in post-conflict regions that combine infrastructure reconstruction with vocational training; community-based security initiatives that reduce violence and stimulate local commerce; and judicial transparency reforms that curb corruption and expand access to public services. Finally, the paper proposes a framework for policymakers to align security sector reform with the 2030 Agenda, emphasizing participatory governance, conflict-sensitive economic planning, and multi-stakeholder partnerships. By situating peace and security at the heart of sustainable development policy, this paper argues that durable economic progress is achievable only when rooted in social cohesion, institutional accountability, and a shared commitment to non-violent conflict resolution.

Keywords: social cohesion, institutional accountability, Sustainability, socio and economic development

1. INTRODUCTION

The nexus between peace and development has gained unprecedented recognition in international policy discourse, particularly following the adoption of the 2030 Agenda for Sustainable Development. Sustainable Development Goal 16, which explicitly calls for "peaceful and inclusive societies for sustainable development," represents a paradigm shift in how the global community conceptualizes the relationship between security and socio-economic progress. This transformation reflects growing empirical evidence that peace and prosperity are not merely complementary objectives but fundamentally intertwined prerequisites for sustainable development.

The economic costs of conflict are staggering. Research demonstrates that countries experiencing intense violent conflict suffer an average annual GDP growth reduction of approximately 2.5 percentage points, while the World Bank estimates that armed conflict costs Sub-Saharan Africa approximately 30% in GDP growth annually. Beyond these immediate economic losses, conflict systematically destroys the institutional foundations necessary for long-term development, eroding trust between citizens and states, disrupting social cohesion, and creating conditions that perpetuate cycles of violence and underdevelopment.

Conversely, countries with high levels of peace demonstrate significantly superior economic performance. Over the past sixty years, very peaceful countries have recorded GDP growth rates two percentage points higher than low-peace countries. This "peace dividend" manifests through multiple channels: enhanced business confidence, improved access to credit, reduced transaction costs, and more effective resource allocation away from security expenditures toward productive investments in human capital and infrastructure.

This paper argues that peacebuilding represents not merely a precondition for development but an active catalyst that accelerates sustainable socio-economic progress. By examining the mechanisms through which peace interventions translate into economic gains, analyzing successful case studies of integrated peace-development approaches, and proposing a framework for aligning security sector reform with the 2030 Agenda, this analysis demonstrates that sustainable development is achievable only when anchored in comprehensive peace building strategies.

2. THE DESTRUCTIVE IMPACT OF CONFLICT ON DEVELOPMENT

2.1. Economic Disruption And Resource Diversion

Violent conflict systematically undermines the foundations of economic development through multiple interconnected pathways. At the macroeconomic level, conflict diverts substantial public resources from productive investments toward security expenditures, creating what economists term "opportunity costs" that compound over time. Countries experiencing high-intensity conflicts face not only immediate productivity losses but also long-term constraints on their development trajectory. The destruction of physical capital represents one of the most visible impacts of conflict. Infrastructure critical for economic activity—roads, bridges, power grids, telecommunications networks—becomes targeted during warfare, disrupting supply chains and market integration. Agricultural production, which employs the majority of the population in many developing countries, suffers particularly severe disruption as farmers abandon their land, irrigation systems are destroyed, and livestock is killed or stolen.

Human capital formation, the cornerstone of long-term economic growth, faces equally devastating impacts. Educational systems collapse as schools are destroyed or converted to military use, teachers flee, and families prioritize immediate survival over long-term investments in education. Healthcare systems similarly deteriorate, leading to increased mortality and morbidity that reduces the productive capacity of the workforce.

2.2. Institutional Degradation And Market Failure

Beyond physical destruction, conflict erodes the institutional foundations necessary for market-based economic development. Property rights become insecure, contracts cannot be enforced, and the rule of law breaks down. This institutional degradation creates an environment of high transaction costs and uncertainty that discourages both domestic and foreign investment. Research demonstrates that conflict particularly affects smaller domestic enterprises, which lack the resources to adapt to increasing security costs and uncertainty. As social capital decreases during times of conflict, businesses retreat into informal and subsistence sectors, creating value chains of minimal length and reducing the complexity of economic interactions that drive productivity growth.

The breakdown of trust—both horizontal trust between citizens and vertical trust between citizens and state institutions—represents perhaps the most insidious long-term impact of conflict on development prospects. Without trust, the collective action necessary for public goods provision, democratic governance, and market transactions becomes impossible, creating conditions that perpetuate underdevelopment even after active hostilities cease.

3. PEACE BUILDING MECHANISMS FOR DEVELOPMENT ACCELERATION

3.1. Security Sector Reform And Economic Confidence

Security Sector Reform (SSR) has emerged as a critical mechanism for translating peace initiatives into economic development outcomes. Comprehensive SSR addresses not merely the technical capacity of security forces but the broader governance framework within which security is provided, emphasizing democratic civilian control, transparency, and accountability. Effective SSR contributes to economic development through multiple channels. First, it improves the business environment by reducing crime, ensuring property rights protection, and creating predictable legal frameworks that encourage investment. Research demonstrates strong correlations between governance indicators related to security provision and measures of economic competitiveness.

Second, SSR can directly stimulate economic activity through the reintegration of ex-combatants into productive employment. Disarmament, Demobilization, and Reintegration (DDR) programs that include vocational training and job placement components not only reduce the risk of conflict recurrence but also contribute human capital to the civilian economy. However, evidence suggests that successful DDR requires coordination with broader economic development strategies to ensure that job opportunities exist for reintegrated combatants.

3.2. Community-Based Security And Local Economic Development

Community policing and participatory security approaches represent particularly promising mechanisms for linking peace initiatives with local economic development. These approaches recognize that security is not merely the absence of violence but the presence of conditions that enable community members to pursue their livelihoods and aspirations. Case studies from Afghanistan, Bangladesh, and Nepal demonstrate how community-police partnerships can stimulate local commerce by reducing crime, improving market access, and building trust between security providers and business communities. In Nepal, working groups that brought together business owners, police, and local government representatives successfully implemented joint security initiatives that included hiring night watchmen, installing CCTV systems, and providing equipment to police forces. These interventions not only improved security but also increased business confidence and reduced the informal taxation imposed by criminal groups.

The participatory nature of these approaches is crucial for their economic impact. By involving local stakeholders in identifying security priorities and designing solutions, community-based security initiatives create ownership and sustainability that top-down approaches often lack. Moreover, they build social capital and trust that facilitates other forms of collective action necessary for local economic development.

4. Transitional Justice And Rule Of Law

Transitional justice mechanisms, including prosecutions, truth commissions, reparations programs, and institutional reforms, play important roles in establishing the rule of law foundations necessary for sustainable economic development. However, research reveals complex relationships between different transitional justice approaches and their economic impacts. Evidence suggests that prosecutions of low- and mid-level human rights violators are associated with decreased likelihood of conflict recurrence, which creates more stable environments for economic activity. Conversely, prosecutions of high-ranking individuals may increase short-term instability, potentially disrupting economic recovery. This finding highlights the importance of sequencing and context-sensitivity in transitional justice programming.

Broader rule of law reforms, including judicial transparency initiatives, contribute to economic development by reducing corruption and improving access to justice. Transparent judicial systems enable businesses to resolve disputes predictably, enforce contracts reliably, and operate within clear regulatory frameworks. Research demonstrates that countries with higher-quality institutions are positively associated with higher average growth rates and lower levels of inequality.

5. CASE STUDIES OF INTEGRATED PEACE-DEVELOPMENT APPROACHES

5.1. Post-Conflict Livelihood Reconstruction In Sri Lanka

The UN Human Security Trust Fund's program in post-conflict Sri Lanka provides a compelling example of how integrated peace-development approaches can improve livelihoods while consolidating peace. Following twenty years of violent conflict and the 2004 tsunami, the program targeted 3,000 households in the conflict-affected districts of Jaffna, Trincomalee, and Batticaloa. The program's success lay in its multi-sectoral, community-based approach that revitalized agricultural activities while strengthening local institutions. Key achievements included: mechanization of crop-tending practices that enabled farmers to increase cultivated land from five to 14 acres; entrepreneurial development activities that engaged vulnerable groups including women, youth, and internally displaced persons; and trade fairs that connected

rural entrepreneurs with local producers and international marketing associations. The program's emphasis on building connections between different stakeholders—farmers, local businesses, government representatives, and international partners—created multiplier effects that extended beyond immediate beneficiaries. A displaced husband and wife team, for example, multiplied their flour production from 35 to 250 packages per month after participating in training programs.

5.2. Infrastructure Reconstruction And Skills Development In India

India's National Highways and Infrastructure Development Corporation (NHIDCL) has implemented large-scale programs that combine infrastructure reconstruction with vocational training, demonstrating how peace-supporting development can be integrated into major infrastructure projects. Under the Recognition of Prior Learning (RPL) scheme, projects with values exceeding Rs. 100 crores must include skill development components for local populations. Between 2018-2022 the program trained over 7,000 workers from conflict-affected regions including Assam, Tripura, Nagaland, and Jammu & Kashmir in construction trades such as masonry and bar-bending. The program included both vocational training for unemployed youth (three-month duration with Rs. 15,000 monthly stipends) and on-the-job training for existing construction workers.

This approach demonstrates how major infrastructure investments can be designed to maximize peace dividends by providing immediate employment opportunities, building local skills, and creating demonstration effects that encourage further private sector investment. The focus on conflict-affected regions explicitly recognizes the role of economic opportunity in consolidating peace.

6. Judicial Transparency And Anti-Corruption Reforms

International experiences in judicial reform demonstrate how transparency initiatives can simultaneously strengthen rule of law and improve economic conditions. The UNDP's work in countries including Afghanistan, Bosnia and Herzegovina, Colombia, Indonesia, Kenya, Kosovo, Nepal, Nigeria, Paraguay, Philippines, and Somalia shows that opening judicial systems fosters integrity without impeding judicial independence. Successful transparency initiatives include: computerized case-tracking systems that limit individual discretion in file management; public disclosure of judicial decisions and reasoning; asset disclosure requirements for judges; and formal institutional mechanisms to ensure parties understand their rights and procedures. These reforms reduce opportunities for corruption while improving the predictability of legal outcomes that businesses require for long-term planning.The economic impact of judicial transparency operates through multiple channels. Reduced corruption lowers transaction costs and creates more level playing fields for businesses. Improved contract enforcement encourages longer-term investments and more complex economic relationships. Enhanced access to justice enables small businesses and individuals to seek redress for grievances without resorting to violence or informal mechanisms.

7. FRAMEWORK FOR ALIGNING SECURITY SECTOR REFORM WITH THE 2030 AGENDA

7.1. Participatory Governance And Inclusive Decision-Making

Sustainable Development Goal 16.7 calls for "responsive, inclusive, participatory and representative decision-making at all levels". Achieving this target requires governance reforms that go beyond formal institutional changes to address the social and cultural foundations of participation. Effective participatory governance in post-conflict contexts must account for power imbalances, trauma, and mistrust that conflict creates. Multi-stakeholder processes offer promising approaches for building participatory governance while consolidating peace. These processes bring together diverse actors—government representatives, civil society organizations, private sector actors, and community leaders—to jointly analyze conflicts, develop strategies, and implement solutions. However, success requires careful attention to legitimacy, power dynamics, and ownership to avoid reproducing exclusions that may have contributed to conflict.

Evidence from Kenya's prevention of election violence demonstrates how multi-stakeholder approaches can effectively combine peace and development objectives. Technical teams comprising media representatives, private sector actors, peace organizations, and manufacturers' associations provided critical analysis and solutions while building relationships that outlasted specific interventions.

7.2. Conflict-Sensitive Economic Planning

Conflict-sensitive development approaches recognize that external assistance, including development aid, becomes part of the context in which it operates and can either exacerbate or mitigate conflict risks. This recognition requires systematic analysis of how development interventions interact with conflict dynamics and deliberate design choices to maximize peace-supporting impacts while minimizing harm. Key principles of conflict-sensitive economic planning include: comprehensive conflict analysis that identifies root causes, triggers, and accelerating factors; attention to distributional impacts that address grievances related to inequality and exclusion; sequencing of interventions to build confidence and demonstrate early wins; and monitoring systems that track both development and peace outcomes.

The UNDP's guidance on governance in conflict prevention and recovery emphasizes that democratic governance interventions must be grounded in thorough analysis that addresses the complex dynamics of violence. Treating inherently political issues as merely technical problems may be conflict-inducing, while properly designed interventions can contribute to both conflict prevention and development.

8. Multi-Stakeholder Partnerships For Sustainability

The 2030 Agenda explicitly recognizes that achieving sustainable development requires partnerships that bring together governments, civil society, private sector, and international organizations. In conflict-affected contexts, these partnerships face additional challenges related to trust deficits, security concerns, and institutional weaknesses, but they also offer unique opportunities to build social cohesion while advancing development objectives. Successful multi-stakeholder partnerships for peace and development share several characteristics: clear common purposes that unite diverse actors; inclusive processes that address power

imbalances and ensure meaningful participation; flexible structures that can adapt to changing contexts; and sustained engagement that allows relationships to develop over time.

The Niger Delta's Partners for Peace (P4P) platform provides an example of how multi-stakeholder partnerships can support both peacebuilding and development. P4P facilitates grassroots conflict analysis and early warning while identifying and supporting initiatives that address conflict risk factors. The platform's emphasis on building local ownership and social capital creates foundations for both peace and development.

9. SOCIAL COHESION, INSTITUTIONAL ACCOUNTABILITY, AND NON-VIOLENT CONFLICT RESOLUTION

9.1. The Foundation Of Social Cohesion

Social cohesion—defined as the inclusiveness of a country's communities and the strength of relationships within and between groups—emerges as a critical foundation for both peace and development. Research demonstrates that socially cohesive societies are better able to implement development policies, respond to shocks, and manage conflicts peacefully. Social cohesion operates through three dimensions: bonding (relationships within groups), bridging (relationships between different groups), and linking (relationships between communities and institutions). All three dimensions are essential for creating the trust and collective action capacity necessary for sustainable development, but conflict often damages these relationships by creating divisions, destroying social networks, and eroding trust in institutions.

Rebuilding social cohesion requires deliberate interventions that address the legacy of conflict while creating new opportunities for positive interaction. Successful approaches include: joint economic projects that create incentives for cooperation between formerly antagonistic groups; inclusive service delivery that demonstrates state responsiveness to all citizens; and dialogue processes that allow communities to process trauma and envision shared futures.

9.2. Institutional Accountability And Development Effectiveness

Institutional accountability—the mechanisms through which public institutions are held responsible for their actions and decisions—plays a crucial role in translating peace dividends into sustainable development outcomes. Without accountability, resources may be captured by elites, public services may not reach intended beneficiaries, and grievances may accumulate that threaten peace.

Effective accountability requires both formal institutional mechanisms (oversight bodies, audit systems, legal frameworks) and informal social mechanisms (civil society monitoring, media scrutiny, citizen engagement). In post-conflict contexts, formal mechanisms may be weak or compromised, making social accountability particularly important for ensuring that peace dividends benefit broad populations rather than narrow elites.

Evidence from the Middle East and North Africa demonstrates that social cohesion and institutional quality interact to determine the effectiveness of public policies. In environments with low institutional quality, social cohesion alone cannot ensure effective development outcomes. However, when institutions cross a threshold of quality, social cohesion significantly enhances policy effectiveness.

9.3. Non-Violent Conflict Resolution And Economic Progress

Non-violent conflict resolution mechanisms provide alternatives to violence that can prevent conflicts from escalating while creating opportunities for negotiated solutions that address underlying grievances. These mechanisms range from traditional dispute resolution systems to formal mediation and arbitration processes, but all share the principle that conflicts can be resolved through dialogue and negotiation rather than force. The economic benefits of non-violent conflict resolution operate through multiple channels. First, preventing violent escalation avoids the destruction and displacement that conflicts cause. Second, negotiated solutions can address underlying grievances related to resource distribution, service delivery, and political participation that may fuel conflicts. Third, successful non-violent resolution builds confidence in institutions and social processes that encourages long-term investments and planning.

India's experience with non-violent conflict resolution demonstrates both the potential and the challenges of these approaches. Traditional practices of dialogue and consensus-building have been effective at the local level but have largely disappeared from political processes. Revitalizing these practices while adapting them to contemporary contexts could provide models for other countries seeking to combine peace and development objectives.

10. IMPLICATIONS FOR POLICY AND PRACTICE

10.1. Designing Integrated Peace-Development Strategies

The evidence reviewed in this paper suggests that sustainable development requires integrated strategies that address both peace and development objectives simultaneously rather than sequentially. This integration must occur at multiple levels: policy frameworks that align peace and development goals; institutional arrangements that coordinate across sectors; programming approaches that address both immediate needs and long-term transformation; and monitoring systems that track progress on both peace and development outcomes.

Successful integration requires recognition that peace and development interventions can have unintended consequences that undermine either objective. Development programs that exacerbate inequalities or exclude certain groups may fuel conflicts, while peace interventions that freeze unjust structures may perpetuate grievances that threaten long-term stability. Addressing these risks requires conflict-sensitive approaches that systematically analyze and mitigate potential negative impacts while maximizing positive synergies.

10.2. Building Implementation Capacity

Implementing integrated peace-development strategies requires capacities that go beyond traditional development or security programming. These include: conflict analysis skills

that can identify risks and opportunities; facilitation skills that can bring together diverse stakeholders; adaptive management skills that can adjust programs based on changing contexts; and systems thinking skills that can understand complex interactions between peace and development factors.

Building these capacities requires investments in training, institutional development, and knowledge management systems that can capture and share lessons learned. It also requires organizational cultures that embrace learning and adaptation rather than rigid adherence to predetermined plans.

10.3. Measuring Peace Dividends

Demonstrating the economic returns to peace building investments requires measurement approaches that can capture both quantitative and qualitative changes across multiple dimensions. Traditional economic indicators such as GDP growth, employment rates, and investment levels provide important baselines, but they must be supplemented with indicators that capture institutional changes, social cohesion, and conflict dynamics. The Institute for Economics and Peace has developed comprehensive frameworks for measuring both negative peace (absence of violence) and positive peace (presence of conditions that support peace). These frameworks provide models for developing context-specific measurement approaches that can track progress and guide adaptive management.

11. CONCLUSION

This paper has demonstrated that peacebuilding represents not merely a precondition for sustainable development but an active catalyst that accelerates socio-economic progress through multiple interconnected pathways. The evidence reviewed shows that countries with high levels of peace consistently outperform less peaceful countries on measures of economic growth, business confidence, institutional effectiveness, and social wellbeing. The mechanisms through which peace translates into development outcomes are complex and context-specific, but they consistently involve improvements in social cohesion, institutional accountability, and non-violent conflict resolution capacity. Security sector reform, transitional justice processes, community-based security initiatives, and judicial transparency reforms all contribute to creating environments conducive to investment, entrepreneurship, and collective action for development.

Case studies from Sri Lanka, India, Kenya, Nepal, and other contexts demonstrate that integrated approaches combining peace and development objectives can achieve superior outcomes compared to sectoral interventions. These approaches require careful attention to participation, conflict-sensitivity, and multi-stakeholder engagement, but they offer pathways for achieving the transformational change envisioned in the 2030 Agenda for Sustainable Development.

The framework proposed in this paper emphasizes three critical elements for aligning security sector reform with sustainable development objectives: participatory governance that ensures inclusive decision-making; conflict-sensitive economic planning that addresses both development needs and peace requirements; and multi-stakeholder partnerships that bring together diverse actors around common purposes. Looking forward, achieving the vision of peaceful and inclusive societies for sustainable development will require continued innovation in integrated peace-development approaches, sustained investments in institutional capacity, and measurement systems that can capture the complex interactions between peace and development outcomes. Most fundamentally, it will require recognition that durable economic progress is achievable only when rooted in social cohesion, institutional accountability, and a shared commitment to non-violent conflict resolution.

The implications of this analysis extend beyond post-conflict contexts to all societies seeking sustainable development. In an interconnected world facing complex challenges from climate change to technological disruption to demographic transitions, the capacity to manage conflicts peacefully while maintaining social cohesion will determine which societies can adapt and thrive. Investing in peace building capacity is therefore not merely a moral imperative but an economic necessity for sustainable development in the 21st century. By situating peace and security at the heart of sustainable development policy, policymakers can harness the peace dividend to accelerate progress toward inclusive, sustainable, and resilient societies. The evidence is clear: peace pays, and investing in peace building is investing in sustainable development.

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ISSN : 2347-6184

Journal of Indian Institute for Engineering, Management and Science

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www.rajshree.ac.in | www. jiiemsr@gmail.com | info@rajshree.ac.in