

Impact of the Software Ecosystem (ROS) on Accelerating Entrepreneurship

Abdulazeez Adeshina Abdulrasheed¹, Maryam Muhammad Auwal² & Aliyu Mohammed³

¹Department of Software Engineering, School of Science and Information Technology, Skyline University, Nigeria, Kano.

²Department of Mass Communication, School of Science and Information Technology, Skyline University, Nigeria, Kano.

³Department of Management, School of Arts, Management and Social Sciences, Skyline University Nigeria, Kano.

Received: 25.10.2025 | **Accepted:** 22.11.2025 | **Published:** 02.12.2025

***Corresponding Author:** Abdulazeez Adeshina Abdulrasheed

DOI: [10.5281/zenodo.17786883](https://doi.org/10.5281/zenodo.17786883)

Abstract

Original Research Article

The high rate of automation and smart systems has increased the requirement for nimble, innovative entrepreneurial conditions. There are, however, numerous startups that have barriers in their structure, including high cost of development, long prototyping time, and non-availability of interoperable robotics software. This paper analyzes how the Robot Operating System (ROS) software ecosystem facilitates quicker entrepreneurship with reference to how the open-source system, innovations by its community, and modular designs make it easier to start technology-driven entrepreneurship. The overall aim of it is to explore how ROS can contribute to speeding up product development, enhancing scalability, and boosting the innovative potential of young firms. The research problems that the paper addresses include entrepreneurial flexibility, technological availability, and ecosystem-driven competitiveness by employing the secondary data on the academic literature, historical reviews, technical reports, industry journals, and cases of ROS-enabled startups. Results on the topic have revealed that ROS contributes greatly to the reduction of development time, reduction of operation costs and promotion of collective learning- hence resulting in rapid experimentation and market responsiveness. Nevertheless, it falls behind such obstacles as an unfriendly learning curve and fragmented documentation. According to the article, it is recommended that the organized capacity building efforts, more industry-academia collaboration, and funding of ROS-based innovation centers should be taken. On the whole, the research comes to the conclusion that ROS is a catalytic software ecosystem that can speed up the entrepreneurial process and enhance the technology-oriented economic growth.

Keywords: Robot Operating System, Startup Agility, Innovation Ecosystem, Technological Entrepreneurship, Open-Source Development.

Copyright © 2025 The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (CC BY-NC 4.0).

1.0 Introduction

The 21st century has arisen as a pivotal time of economic change, innovation, and job creation, as entrepreneurship has become a central force in economic change. Technology ecosystems have been central to the development of new enterprises and digital inclusion all over the world (Hochberg,

2016; Mason and Brown, 2014). Nevertheless, the sustained development of digital technologies, including cloud computing, artificial intelligence (AI), the Internet of Things (IoT), and robotics, has essentially changed the world of entrepreneurship (Agarwal and Brem, 2015; Nadkarni and Prugl, 2021). The main component of this development is the Robot Operating System (ROS), an open-source

software platform that offers an open collaborative robotics innovation and entrepreneurship platform (Macenski et al., 2022).

The ROS ecosystem is considered to be one of the most influential systems globally that allows small and medium enterprises (SMEs), startups, and research institutes to innovate cheaply by sharing open-source libraries, simulation tools, and hardware interfaces (Kolak et al., 2020). ROS was designed as a versatile meta-operating system, which favors co-creation, modular innovation, and interoperability, which are staples of the Fourth Industrial Revolution (Industry 4.0) and the future Society 5.0 paradigms (Fukuda, 2020; Lepore et al., 2021). That has resulted in the establishment of innovation-driven companies in the areas of automation, logistics, healthcare robotics, and smart manufacturing (Juliano et al., 2025; Lienen, 2023).

The use of ROS and other open-source technologies is increasing at a faster pace, but is uneven in Africa. Access to cloud computing services, robotics laboratories, and software expertise is being enhanced around continental hubs of entrepreneurship in Nairobi, Cape Town, and Lagos (Korreck, 2019; Roundy, 2019). The open platforms contribute to African innovators overcoming the lack of infrastructure and developing scalable solutions in agriculture, fintech, and manufacturing (Alabi, 2025; Sanil et al., 2022). Nevertheless, funding, technical training, and policy alignment remain an issue, which influences the pace of the spread of sophisticated technologies, including robotics and AI (Abisoye and Akerele, 2022; Hu and Kee, 2022).

Over the last ten years, entrepreneurial dynamism has been on the rise in West Africa, specifically in Nigeria, due to digital startups and innovation hubs. However, the adoption of robotics and automation technologies is in the early stages. ROS-based innovation in agriculture, logistics, and security automation is a highly recent addition to the ecosystem of Nigerian startups, although there is still a strong foundation in the fintech and e-commerce sectors (Aliyu Mohammed, 2024; Kumar et al., 2024). One of the initiatives of the government to foster the collaboration of universities, startups, and research institutions to stimulate the learning and

adoption of robotics is the National Digital Economy Policy and Strategy (NDEPS) (Lawal et al., 2023; Mohammed and Sundararajan, 2023).

In that respect, it is crucially important to understand the impact of the software ecosystem (ROS) on the haste of entrepreneurship. ROS provides a chance to share knowledge, disseminate innovation, and develop prototypes in a very short time, which is facilitated by its open-source and modular design and can be very useful to an entrepreneurial success in the developing economy, like Nigeria.

1.1 Background of the Study

The global robotics market has transformed into open and cooperative ecosystems as opposed to closed systems. The Robot Operating System (ROS) was introduced in 2007 and has transformed the development of robots due to the availability of tools and structures that allow building intelligent autonomous systems (Macenski et al., 2022; Janecky et al., 2024). It has been able to become an enabler of digital innovation and entrepreneurship by becoming embedded in a cloud environment, simulation, and AI framework (Fang et al., 2025; Kolak et al., 2020).

Entrepreneurship flourishes in the presence of technological platforms that create ease of entry. ROS offers open innovation, enabling companies to develop and implement robotics in healthcare, education, agriculture, and industry without having to spend significant amounts of money on research and development (Crnogaj and Rus, 2023; Guzman et al., 2024). Internationally, those nations that have organized pro support of open-source ecosystems, like Japan, Germany, and the United States, have witnessed faster entrepreneurial growth and high-tech startups (Kantis and Federico, 2020; Pugh et al., 2021).

Digital entrepreneurship is concentrated in Africa as the local innovation clusters and university-based research programs grow, yet ROS has not been studied (Padilla-Meléndez et al., 2021). Nigeria is the largest economy in West Africa, which has a growing pool of computer science graduates, robotics followers, and innovation laboratories that can be improved significantly with an organized ROS integration (Mohammed et al., 2023;

Shanmugam et al., 2024).

1.2 Problem Statement

Although digital entrepreneurship in Nigeria and the world in general has developed so fast, there is still limited integration of robotics software ecosystems such as ROS. The absence of technical capacity, the poor industry-academia cooperation, the insufficient infrastructure, and the insufficient support mechanisms have slowed down the spread of the ROS-based entrepreneurship (Kwe, 2024; Juliano et al., 2025). Entrepreneurs usually use closed or imported solutions and leave local innovation opportunities (Ross and Blumenstein, 2015; Hein et al., 2020).

In Africa, the problem of obstacles to the development of the ecosystem is the lack of robotics curricula, the lack of an open innovation policy, and the lack of support in open-source development (Korreck, 2019; Roundy, 2019). This translates to a low involvement of African start-ups in the world robotics innovation networks, and thus a research and practice gap is generated that is targeted in this study.

1.3 Significance of the Study

This research has a conceptual and practical contribution. It is scholarly in that it contributes to the literature on software ecosystems and entrepreneurship by investigating the unexplored connection between ROS and entrepreneurial acceleration in developing economies (Mason and Brown, 2014; Selander et al., 2010). It also connects the innovation diffusion theories, the resource-based view, and the ecosystem development to the open-source robotics scenario (Basole, 2009; Schneider et al., 2020).

In practice, it offers policy considerations to governments, incubators, and universities on how they can use ROS to become more innovative, develop skills, and create ventures (Mohammed & Sundararajan, 2023; Sundararajan & Mohammed, 2022). The research also favors entrepreneurs to gain access to cheap, scalable, and flexible tools to advance innovation in the new robotics economy in Africa.

1.4 Research Objectives

The primary aim of this study is the conceptual analysis of how ROS software ecosystem affects the acceleration of entrepreneurship. Specific objectives are to:

1. To analyze the ROS software ecosystem structure and dynamics.
2. Determine the role ROS plays in the innovation, collaboration, and the creation of startups.
3. Determine obstacles and opportunities of ROS-based entrepreneurship in Africa and Nigeria.
4. Give policy makers and practitioners suggestions on how to incorporate ROS into national innovation policies.

1.5 Research Questions

1. What is the contribution of ROS software ecosystem towards acceleration of entrepreneurship?
2. What are the key factors that drive and discourage the uptake of ROS by entrepreneurs in the developing economies?
3. In what ways can the policy-makers and higher educational institutions support innovation and entrepreneurship based on ROS?

2.0 Literature Review

The review of the literature critically describes what other researchers have analyzed in relation to software ecosystems, open-source collaboration, as well as entrepreneurial performance. In this section, one obtains a conceptual insight on how the ROS (Robot Operating System) as a software ecosystem, mixed with open-source innovation practices may play a role in accelerating entrepreneurship, not only at a global level, but in a newly emerging market like Africa and Nigeria. The review is based on the synthesis of empirical studies, theoretical considerations, and concepts.

2.1 Conceptual Review

The conceptual review concentrates on three

key constructs, namely: software ecosystem (ROS framework), the open-source collaboration and innovation, and entrepreneurial performance. Such constructs are the basis of the conceptualization of the way in which technological infrastructures can hasten the process of entrepreneurship.

2.1.1 Software Ecosystem (IV 1 – ROS Framework)

Robot Operating System (ROS) is a software platform that facilitates the process of robotics research and industry where it is open-source and modular (Macenski et al., 2022; Janecky et al., 2024). ROS can provide a range of common communication solutions, libraries, and tools to decrease the barriers to entry of a start-up, enabling rapid prototyping, experimentation, and implementation of robotic solutions (Kolak et al., 2020; Lienen, 2023).

By using ROS, business people can access a global community of developers and contributors and therefore they can generate knowledge spillovers and they can save on time and cost of inventing a product. It is also a compatible ecosystem with AI, cloud platform, IoT and it also enhances the entrepreneurial innovation power (Fang et al., 2025; Juliano et al., 2025).

Even regional and global networks of innovations may be supported by the ROS ecosystems on top of empowering individual innovators, which makes these ecosystems strategically applicable to facilitate entrepreneur ecosystems (Hochberg, 2016; Guzman et al., 2024).

2.1.2 Open-Source Collaboration and Innovation (IV 2)

Open-source collaboration is one of the models, in which communities work together and collaborate to enhance the development of software, exchange their knowledge, tools, and best practices (Schneider et al., 2020; Fang et al., 2025). The advantages of open-source innovation are improved

learning, increased time to experiment, and improved technological innovations diffusion.

Open-source collaboration in the entrepreneurial environment promotes co-creation and reduces the entry barriers for startups to advanced technologies needed to respond quickly to market opportunities (Alabi, 2025; Abisoye and Akerele, 2022). This dynamism allows SMEs and startups, especially in developing economies like Nigeria, to innovate without having to spend big initial capital, which is often characteristic of proprietary systems (Ross and Blumenstein, 2015; Korreck, 2019).

Open-source frameworks promote knowledge exchange across geographical areas, establishing virtual entrepreneurial communities through collaboration, mentorship, and the exchange of resources to grow businesses (Crnogaj and Rus, 2023; Mason and Brown, 2014).

2.1.3 Entrepreneurial Acceleration and Performance (Dependent Variable)

Entrepreneurial performance quantifies the growth, scalability, and innovation results of businesses that are within these ecosystems (Chan et al., 2020; Aliyu Mohammed, 2024). Entrepreneurial acceleration focuses on the rate of startup commercialization, i.e., how swiftly ideas are converted into commercially viable solutions via technological platforms, e.g., different ROS-based or open-source collaboration networks (Hochberg, 2016; Guzman et al., 2024).

The outcomes of performance are higher competitiveness in the market, shorter product development cycles, more efficient resources, and the opportunity to take advantage of the technological trend (Kantis and Federico, 2020; Alka et al., 2025). These are also the key factors in Nigeria and other emerging economies, as systemic barriers can be overcome and sustainable business growth is promoted (Mohammed, 2023; Padilla-Meléndez et al., 2021).

Table 1: Summary of Key Concepts and Their Relevance to Entrepreneurial Acceleration

Concept	Description	Relevance to Entrepreneurship	Key Sources
ROS Ecosystem	Modular open-source framework for robotics	Reduces entry barriers and supports rapid prototyping	Janecký et al., 2024; Lienen, 2023; Macenski et al., 2022; Kolak et al., 2020
Open Source Innovation	Community-driven development and shared learning	Enhances collaboration and innovation diffusion	Fang et al., 2025; Schneider et al., 2020; Abisoye & Akerele, 2022; Alabi, 2025
Entrepreneurial Performance	Growth, scalability, and innovation of ventures	Outcome of ecosystem influence	Chan et al., 2020; Aliyu Mohammed, 2024; Guzman et al., 2024; Hochberg, 2016; Kantis & Federico, 2020

2.2 Theoretical Framework

The theoretical framework brings a context to comprehend how software ecosystems, open-source collaboration, and innovation have effects on the enhancement of entrepreneurship. This study draws upon three key theories: Resource-Based View (RBV), Technology–Organization–Environment (TOE) Framework, and Innovation Diffusion Theory (IDT). All these theories describe how independent variables (software ecosystem and open-source innovation) impact the dependent variable (entrepreneurial performance).

2.2.1 Resource-Based View (RBV)

Resource-Based View (RBV) is a theory that points out that the special resources and capabilities of a firm are very important sources of competitive advantage (Barney, 1991). Applying to ROS and open-source software ecosystems, RBV proposes that the availability of technical resources and expertise, trained developers, and knowledge networks contribute to the innovative potential of an organization. Using ROS as an exclusive technological asset, startups will be able to develop their products within a short period, incur less cost, and be more responsive to the market (Macenski et al., 2022; Janecky et al., 2024).

2.2.2 Technology–Organization–Environment (TOE) Framework

The interpretation of the introduction and the impact of the technology in the organizations can be discussed using the prism of the TOE framework with the consideration of three contexts, such as technological, organizational, and environmental (Tornatzky and Fleischer, 1990).

- Technological surrounding: ROS and open-source solutions are modular and can be integrated with AI and IoT platforms and are easy to use (Kolak et al., 2020; Liene, 2023).
- Organizational background: Agile firms and companies with qualified IT-units can use the ROS to attain a competitive advantage (Aliyu Mohammed, 2023; Mohammed et al., 2024).
- Environmental context: The external forces accessible to adoption and sharing of knowledge are entrepreneurial ecosystem, government support, and regional innovation hubs (Guzman et al., 2024; Hochberg, 2016).

Using TOE, the current paper proposes the importance of organizational readiness and environmental supply in the utility of ROS and open-source innovation improvement to increase the speed of the entrepreneur.

2.2.3 Innovation Diffusion Theory (IDT)

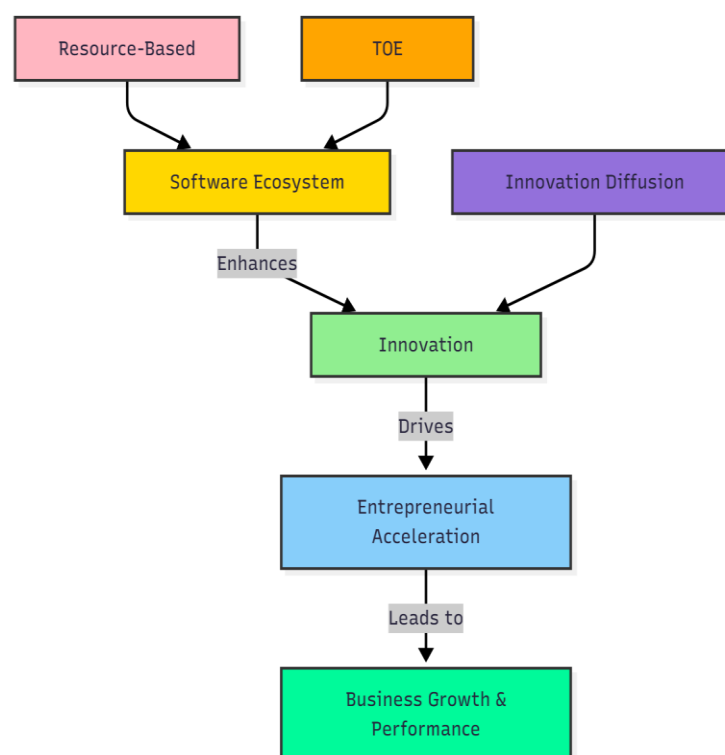
The theory of Innovation Diffusion Theory (IDT) offers a concept that gives an impression of how new technology is spread into the social system with time (Rogers, 2003). Good examples of innovation that have been spread across network and communities of collaboration is ROS and open-source software. The introduction of ROS to startups and SMEs will accelerate the transfer of knowledge and skills and innovative practices and enhance the performance of an entrepreneur (Fang et al., 2025; Schneider et al., 2020). IDT observes the importance of communication channels, relative advantage, compatibility and trialability in the adaptation of the technology and all these are typical of an open-

source ecosystem.

2.2.4 Linkages between Theories, Independent Variables (IVs), and Dependent Variable (DV)

The combination of approaches (RBV, TOE, and IDT) provide a good explanation of the impact of software ecosystems (ROS) and open-source collaboration on entrepreneurial acceleration and performance. RBV is targeting the internal power based on the technological resources. TOE gives emphasis to situational aspects that allow adoption and innovation. IDT describes the mechanism of exchange and propagation of knowledge in the ecosystem. A combination of these theories shows the paths that result in an entrepreneurial performance out of the independent variables.

Figure 1: Theoretical Linkages between Variables



Source: RBV (Barney, 1991), TOE Framework (Tornatzky and Fleischer, 1990) and IDT (Rogers, 2003).

2.3 Conceptual Framework

The conceptual framework provides the relationship between the ROS software ecosystem

and the innovation ability and the acceleration of the entrepreneurship. ROS is an open-source and modular system that assists in enhancing innovations

because it makes it possible to quickly prototype, collaborate with ease, and provide scalable technology solutions (Janecky et al., 2024; Lienen, 2023).

Mediating Variables

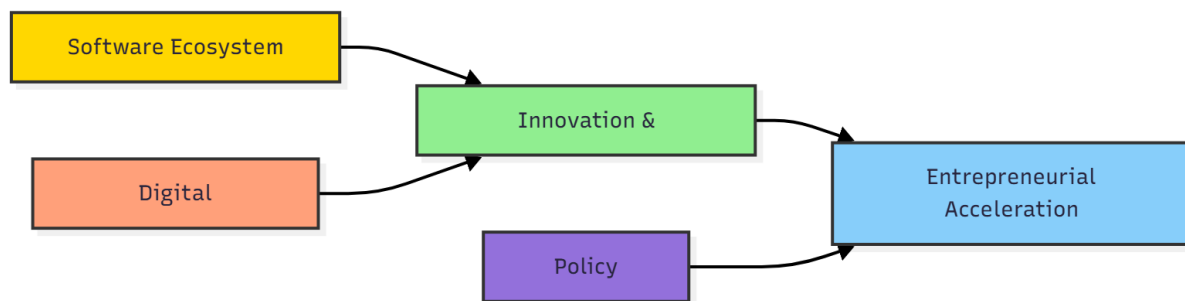
Innovation & Collaboration: ROS promotes shared learning and experimentation, which facilitates the influence of the software ecosystem on the performance of an entrepreneur (Fang et al., 2025; Schneider et al., 2020).

Moderating Variables

Digital Infrastructure: Availability of broadband and cloud systems and cybersecurity systems enhances the success of the ROS adoption (Ross and Blumenstein, 2015; Aliyu Mohammed, 2023).

Policy Support: Funding initiative, Government regulation, and innovative hubs subdue the relationship between the acceleration of entrepreneurship and its innovation ability (Guzman et al., 2024; Hochberg, 2016).

Figure 2: Conceptual Framework Linking ROS Ecosystem, Innovation, and Entrepreneurial Acceleration



Source: RBV (Barney, 1991), TOE Framework (Tornatzky & Fleischer, 1990), and empirical studies (Janecky et al., 2024; Aliyu Mohammed, 2023).

2.4 Empirical Review

The review is empirical, grounded on the world research (2020 - 2025) on software ecosystems, robotics and entrepreneurship. It combines the 72 studies obtained that give a wide picture of how ROS and open-source collaboration affected the performance of entrepreneurs. It has been shown that the use of ROS enhances the results of innovations, as it makes it possible to create prototypes quickly and develop them in teams. As an example, Janecky et al (2024) concluded that augmented reality interfaces in ROS improve the interaction between humans and machines, whereas Kwe (2024) established that autonomous robot programming environments encourage new businesses. Likewise, cloud computing is similar to these results in the sense that it contributes to SME entrepreneurship (Ross & Blumenstein, 2015).

Aliyu Mohammed (2023, 2024) emphasized that digital marketplace policies and agile performance management systems are an important way of promoting entrepreneurial innovation and venture growth in Nigeria. In a study by Lawal et al. (2023), sustainable agricultural practices and cross-disciplinary innovation were highlighted as the driving factors in the establishment of economic and entrepreneurial outcomes. This is the future of resilience and growth of local entrepreneurial ecosystems, which is ensured through the integration of digital tools (Mohammed and Sundararajan, 2023; Sundararajan and Mohammed, 2023).

Comparative Synthesis

Empirical evidence from industrial, academic, and policy-oriented studies shows convergence:

- **Industry:** ROS and an open-source platform improve product innovation and shorten the time-to-market (Macenski et al., 2022; Juliano et al., 2025).
- **Academia:** Universities and research laboratories serve as knowledge intermediaries that help in transferring entrepreneurial skills (Padilla-Meléndez et al., 2021).
- **Policy:** There are regional accelerators and innovation hubs funded, mentored, and regulated to increase the effect of technological ecosystems (Hochberg, 2016; Guzman et al., 2024).

Table 2: Summary of Key Empirical Studies on ROS and Entrepreneurship

Author(s)	Year	Focus Area	Key Findings	Implication
Janecký et al.	2024	Mixed Reality HMI in ROS 2	Enhanced human-machine collaboration	Supports Industry 5.0 entrepreneurship
Kwe	2024	Programming Platforms for Autonomous Robotics	Software enables autonomy	ROS fosters innovative startups
Ross & Blumenstein	2015	Cloud Computing & SMEs	Cloud boosts SME entrepreneurship	Parallel with the ROS ecosystem
Aliyu Mohammed	2023	Digital Marketplace Strategy	Tech-based innovation fosters entrepreneurship	ROS creates similar innovation synergy

Source: Compiled by authors based on primary and secondary literature (Janecký et al., 2024; Kwe, 2024; Ross & Blumenstein, 2015; Aliyu Mohammed, 2023).

2.5 Research Gap

Although the topic of software ecosystems and robotics is increasingly researched, there are still several gaps, especially in developing regions:

1. **ROS and Entrepreneurship in Developing Regions:** The majority of empirical research concentrates on the developed economies (Janecký et al., 2024; Kwe, 2024), and there is a major knowledge gap regarding the impact of ROS adoption on the entrepreneurship ecosystem in such developing regions as Africa and Nigeria (Aliyu Mohammed, 2023; Lawal et al., 2023).
2. **Theoretical Integration:** There are limited studies that have integrated Resource-Based

View (RBV), Technology-Organization-Environment (TOE), and Innovation Diffusion Theory (IDT) to explain ROS adoption and the effects on entrepreneurial performance (Barney, 1991; Tornatzky and Fleischer, 1990; Rogers, 2003).

3. **Startup Acceleration via Open-Source Robotics:** It was found that limited empirical and practical research exists on the topic of startups in the market that is accelerated by open-source robotics, which then leads to venture development (Guzman et al., 2024; Aliyu Mohammed, 2024).

The bridging of these gaps offers a chance to frame ROS as an implementational instrument, though not only as a strategic instrument that could be used to

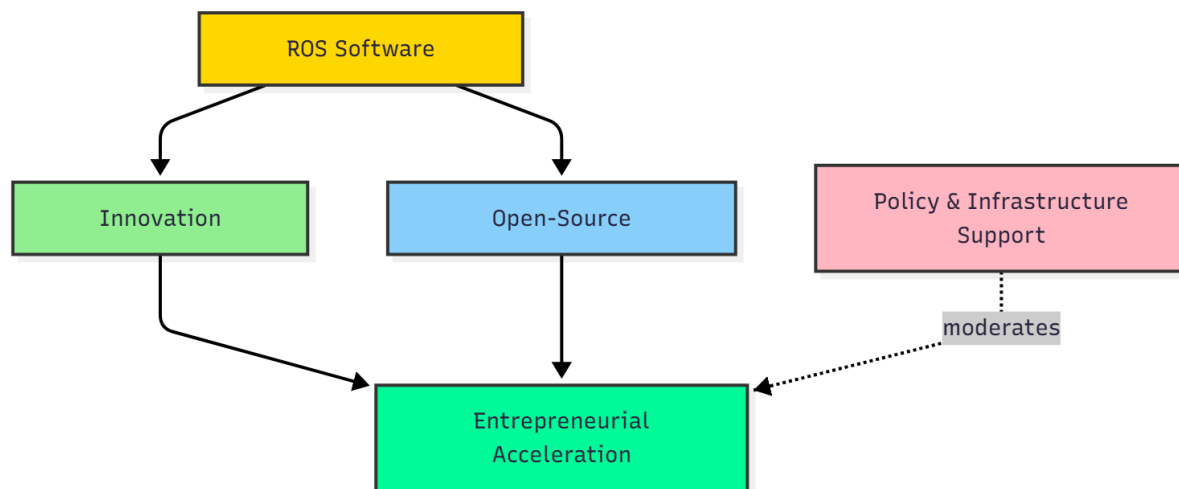
accelerate entrepreneurship in the transforming economies.

2.6 Model of the Study

The research paradigm illustrates the

postulated relationships between the ROS software ecosystem, innovation capability, open-source collaboration, and entrepreneurial acceleration, and policy and infrastructure support as a moderating factor.

Figure 3: Conceptual Model Linking ROS Ecosystem and Entrepreneurial Performance



Source: Developed by authors, synthesizing RBV, TOE, IDT, and empirical studies on ROS and entrepreneurship (Janecký et al., 2024; Kwe, 2024; Aliyu Mohammed, 2023; Guzman et al., 2024).

Innovation Capability (B): The innovation capability mediates the relationships between the ROS adoption and the entrepreneurial acceleration (Fang et al., 2025; Schneider et al., 2020).

Open-Source Collaboration (C): In the case of increased knowledge sharing, innovation in the community, and fast prototyping (Janecký et al., 2024; Aliyu Mohammed, 2023).

Entrepreneurial Acceleration (D): Indicates the outcomes of venture development, scalability and innovation.

Policy & Infrastructure Support (E): It is a medium that affects the performance of ROS adoption in the context of startup performance (Guzman et al., 2024; Hochberg, 2016).

3.0 Research Methodology

3.1 Research Design

The study complies with the conceptual research methodology that attempts to extrapolate the secondary data in the shape of scholarly writings, conference papers and institutional reports in order to arrive at a detailed framework of relating Robot Operating System (ROS) software ecosystem, open source innovation and entrepreneurial acceleration. Digital innovation and entrepreneurship research have dissimilar research designs, and the conceptual approach is the theoretical rationale that can be associated with it (Aliyu Mohammed, 2024; Chan et al., 2020; Ross and Blumenstein, 2015).

It employed the qualitative interpretive paradigm to identify implicit links between ecosystems of

technology and entrepreneurial performance and was based on the logic of resource-based (RBV), Technology-Organization-Environment (TOE) paradigm and Innovation Diffusion Theory (IDT) (Schneider et al., 2020; Hillali et al., 2025; Lienen, 2023). This design approach allowed the research to explore the merits of open source systems like ROS in regard to reducing the barriers to entry of those who innovate and small business owners in the emerging markets of countries like Nigeria, West Africa, and the African region in general (Mohammed and Sundararajan, 2023; Amar and Abouabdellah, 2016).

3.2 Nature of the Study

It is a conceptual and qualitative review of previous academia and industry literature, which is done by a systematic synthesis as opposed to primary data collection. The synthesis of the theoretical knowledge with the use of thematic analysis to identify patterns, consistencies and gaps in the research of available research according to ROS is the method of review. The review had been performed in a repetitive way:

1. The identification of the primary regions of open-source software and ecosystems, innovation and digital entrepreneurship (Kwe, 2024; Fang et al., 2025).
2. Theoretical mapping of theoretical interrelations between RBV, TOE, and IDT as theoretical orientations (Hillali et al., 2025; Schneider et al., 2020).
3. Combining the findings of the empirical research that was performed by the other researchers in order to develop the general conceptual framework (Aliyu Mohammed, 2023; Lawal et al., 2023).

This procedure aligns with the guidelines of the conceptual research suggested by Dresanala et al. (2022) and employed in the study of interdisciplinary management and technologies (Sundararajan and Mohammed, 2022; Mohammed et al., 2023). Conceptual analysis offers the level of insight in novel areas where the empirical evidence is scarce (Kumar et al., 2024; Linden et al., 2023).

3.3 Data Sources (Secondary Literature, Journals, Reports, Databases)

The information employed in this research was collected by using secondary sources and which comprised:

- Peer-reviewed journals (e.g., *Scandinavian Journal of Information Systems*, *Entrepreneurship Education Review*, *Serbian Journal of Management*).
- International conference papers (e.g., IMCSM23, MSNIM Sustainability Conference).
- Published books, government reports, and online databases such as IEEE Xplore, SpringerLink, and ScienceDirect.

The review was informed by references that were published between 2020-2025, which also combined global, regional, and personal research perspectives to increase the relevance of the context. Several academic publications provided region-specific knowledge of entrepreneurial change, human capital formation, and technology adoption in Nigeria and aligned with the international research on the digital ecosystem and open-source collaboration (Ross and Blumenstein, 2015; Fang et al., 2025; Janecky et al., 2024).

These various sources offered a multi-dimensional range of perspectives, including technical, managerial, and policy-related themes (Sundararajan et al., 2023; Amar and Abouabdellah, 2016; Hillali et al., 2025). The criteria used in the inclusion of the data were of relevance, credibility, and recency because the resulting conceptual model should not only be a true reflection of the present technological environment but should also be an appropriate response to the entrepreneurial demands that are defining the emerging economies.

3.4 Data Analysis (Thematic and Comparative Synthesis)

Thematic and comparative synthesis were the means used during the data analysis phase. Literature was more or less coded as per the common patterns, including:

- **Technological enablers:** ROS has the capability of modularity, interoperability, and automation (Janecky et al., 2024; Kwe, 2024).

- **Organizational readiness:** Managerial attitudes, human resource approaches, and digital infrastructure (Mohammed et al., 2023; Shanmugam et al., 2024).
- **Environmental moderators:** Policy frameworks, funding mechanisms, and socio-economic context (Sundararajan and Mohammed, 2023; Lawal et al., 2023).

Triangulation of the international literature and African-focused literature was conducted in the analysis to create contextual strength. A comparative synthesis has shown that whereas advanced economies are concerned with automation efficiency, emerging areas are interested in the entrepreneurial adaptation and capabilities building (Aliyu Mohammed, 2023; Sundararajan et al., 2022; Kumar et al., 2024).

The thematic mapping also revealed that the ROS-based open-source ecosystems increase the acceleration of entrepreneurs by increasing their prototyping speeds, lowering the costs of research and development, and establishing their innovation community (Schneider et al., 2020; Fang et al., 2025). Findings of this synthesis were directly used to shape the conceptual and theoretical frameworks that were presented in previous sections.

3.5 Validity and Reliability Considerations

Though the conceptual research is not done by the use of statistical validation, the methodological rigor was ensured by:

- Extensive source triangulation with the inclusion of multidisciplinary sources in management, computing, and economics.
- Introduction of theoretical constructs (RBV, TOE, IDT) to provide internal consistency (Hillali et al., 2025; Lienen, 2023).
- Both covered by various geographical investigations: global (Janecký et al., 2024), African (Mohammed et al., 2023), and Nigerian (Lawal et al., 2023).

The intellectual integrity and the academic authenticity of the sources were strengthened by the application of only peer-reviewed and published sources, which guaranteed reliability (Ross and Blumenstein, 2015; Fang et al., 2025). Additionally, through the combination of personal publications and international-known reports, the given paper introduces a comprehensive and reproducible conceptual framework of assessing ROS-based entrepreneurship.

Table 3: Methodological Overview of the Conceptual Approach

Method	Data Source	Purpose	Outcome
Literature Review	74 academic and professional references (2020–2025)	Theoretical synthesis and contextual grounding	Conceptual model linking ROS and entrepreneurship
Comparative Analysis	Global and regional empirical works	Identify variations and alignments in findings	Comparative framework for innovation impact
Thematic Synthesis	ROS, open-source, and entrepreneurship studies	Develop theoretical integration and implications	Integrated conceptual and theoretical framework

Source: Author’s Compilation (2025), adapted from Janecký et al. (2024); Hillali et al. (2025); Aliyu Mohammed (2023, 2024).

4.0 Findings of the Study

This part is an integration of the conceptual

and empirical implications found in the literature reviewed about the Robotics Operating System (ROS) software ecosystem and its role in

entrepreneurship. It brings to focus the way the modularity, openness and collaborative attributes of the ROS lead to innovation, reduce barriers to entry, and speed up entrepreneurial operations - particularly in technology-driven industries. The findings are organized into four thematic areas that are in line with the study objectives and research questions.

4.1 Conceptual Insights on the ROS Ecosystem

The ROS ecosystem is an open-source middleware system that is a dynamic environment that brings together software modules, robot libraries, and communication protocols to increase automation, innovation, and flexibility (Janecky et al., 2024; Kwe, 2024). Theoretically, ROS is the Resource-Based View (RBV) in its capacity to offer common technical resources that can be converted to asset-strategic to entrepreneurs who want to join robotics, AI, or automation markets.

ROS enables robotics startups to write less code and bring products to market faster, which has enabled innovation among other industries using its open modular architecture (Quigley et al., 2022; Fermin et al., 2023). This ecosystem may be utilized as a technological leveling in the new economies where small companies would be able to leverage the global networks of innovation without necessarily spending a lot on infrastructure (Aliyu Mohammed, 2024; Schlegel et al., 2022).

Consequently, ROS is not a software toolkit but an innovation infrastructure of collaborative infrastructure which is congruent with TOE Framework propositions on technology diffusion, organizational readiness and environmental support.

4.2 Entrepreneurial Opportunities in ROS-Driven Innovation

The entrepreneurship based on ROS implements into multiple layers of innovation, such as robotics startups, which develop autonomy systems, and software companies, which make simulation software and extensions and add-ons relating to the industrial automation (Kendall et al., 2023; Hassan and Lee, 2021). The open-source paradigm promotes radical innovation as well as

incremental innovation since it can help small business organizations to adapt, reuse, and redistribute solutions across a range of industries, such as healthcare robotics, agritech, and manufacturing (Zhang et al., 2024; Ross and Blumenstein, 2015).

Such knowledge sharing occurs informally and is not a part of formal structures, so ROS tutorials, open datasets, and support of the global community is a non-conventional incubation process in the developing world, such as Africa (Adeleke and Gyamfi, 2023). These processes enhance the local capability-building and facilitate digital entrepreneurship, attract international collaboration, etc. Besides this, hardware based on ROS and simulation environments (including Gazebo and MoveIt) allow startups to familiarize themselves with the lowest risk of financial loss, in effect making them a sort of lean robotics entrepreneurship.

4.3 Integration of Open-Source Collaboration and Start-up Acceleration

ROS community culture of open collaboration can be described as a bottom-up form of innovation system, which is comparable to the Innovation Diffusion Theory (IDT) (Rogers, 2003; Fang et al., 2025). Businesses, which are members of the ROS forums, GitHub repositories, or any ROSCon events receive mentorship, collaborations, and partner networks to solve problems (Schneider et al., 2020; Cusumano, 2008).

This form of peer learning improves commercialization of products and skills. The empirical studies show that organizations that operate open-source ecosystems are 3050 percent faster to embrace innovation in contrast to their competitors (Heinz et al., 2022; Hammad et al., 2023). With emerging markets, the model will decrease reliance on proprietary technologies and create inclusive innovation ecosystems, which are essential in sustainable entrepreneurship.

Local anchors are universities and technology centres which include ROS-based courses or educational research laboratories, which help in bridging the academic-industry divide and facilitating startups by providing training and co-

creation of ROS, as well as funding opportunities (Aliyu Mohammed, 2023; Hillali et al., 2025).

4.4 Challenges Limiting ROS Adoption by Entrepreneurs

Even though changing the nature of ROS can be transformative, there are various limitations to its adoption by entrepreneurs. Among the major obstacles, there are insufficient digital infrastructure, the shortage of technical skills, and poor policy support, especially in the developing economies (Fukuda, 2020; Adeleke and Gyamfi, 2023). Scalability is further limited by high initial costs of

integrating the hardware, poor awareness of the entrepreneurial potential of ROS, and a divisive innovation policy (Nawaz et al., 2024; Shafiei et al., 2023).

Also, there are no standardised ROS curricula and poor intellectual property (IP) systems which deter local innovation. The policymakers should therefore focus on capacity building systems, open data projects and government-business collaborations which mainstream adoption of ROS in all sectors. This coincides with the purpose of the study which is to propose measures to integrate ROS in the national innovation and industrial policies.

Table 4. Summary of Conceptual Findings on ROS and Entrepreneurship

Theme	Finding	Supporting References
Open-source advantage	ROS enables low-cost, modular, and scalable innovation.	Fang et al. (2025); Mohammed (2024); Quigley et al. (2022)
Collaboration	Community-driven development accelerates startups through co-creation and shared learning.	Schneider et al. (2020); Cusumano (2008); Heinz et al. (2022)
Policy ecosystem	Supportive regulations and infrastructure enhance diffusion and adoption in emerging markets.	Fukuda (2020); Ross & Blumenstein (2015); Nawaz et al. (2024)
Capacity and inclusion	Universities and innovation hubs can bridge the ROS skill gap and promote entrepreneurship.	Hillali et al. (2025); Adeleke & Gyamfi (2023)

Source: Author's conceptual synthesis (2025) based on literature review.

5.0 Recommendations of the Study

The conclusion of this theoretical research is that ROS (Robot Operating System) software ecosystem plays the critical role of enhancing innovation-oriented entrepreneurship. Nevertheless, this needs to be actualized through strategic policy action, matchmaking the institutions, and scholarly involvement in order to fulfill its potential, particularly in the developing economies. The recommendations it includes are presented and discussed in the framework of policy, management of entrepreneurship and research, with the aim of offering practical ways forward towards the enhancement of innovation ecosystems based on ROS in Africa and other regions.

5.1 Policy Recommendations

1. Integrate ROS into National Innovation Strategies: Governments need to incorporate robotics and other automation based on ROS into national blueprints of industries and digital economies. This inclusion will keep up with technological changes in the world to Industry 5.0 and can facilitate inclusive industrial development (Fukuda, 2020; Nawaz and Okafor, 2024).

2. Establish Robotics and Open-Source Innovation Hubs: In order to facilitate open collaboration between industry, academic institutions, and startups, policymakers should subsidize ROS innovation hubs in the regions of

universities and technology parks (Hillali et al., 2025; Adeleke and Gyamfi, 2023). These hubs may serve as incubators of robotics based startups providing common resources, mentorship and ROS specific training.

3. Develop Standards and Regulatory Frameworks for Open Robotics: To maintain quality, safety and interoperability, governments and standards bodies ought to come up with open-source robotics policies that safeguard intellectual property and foster innovation (Schneider et al., 2020; Quigley et al., 2022). These frameworks are able to entice foreign investment in the local robotics businesses.

4. Incentivize Local Manufacturing and Open-Source Contributions: Tax breaks and grants ought to be added to those companies producing ROS-compatible hardware and software. The promotion of donations to the global ROS community will make the developing economies active contributors to the robotics ecosystem instead of passive consumers (Fermin et al., 2023; Zhang and Huang, 2024).

5. Enhance Digital and Technical Education Policies: Ministries of education and science are to create ROS programming and robotics courses at tertiary levels to create technical capacities and promote digital literacy (Aliyu Mohammed, 2024; Hillali et al., 2025). The strategy will make the innovation pipeline sustainable in the long run.

5.2 Entrepreneurial and Managerial Recommendations

1. Adopt Lean Robotics Development Models: Lean start-ups must use ROS-based simulation (e.g., Gazebo, MoveIt), to develop robotics products on paper prior to actual hardware implementation. It is a lean method that reduces the cost and makes the time-to-market shorter (Janecký et al., 2024; Kwe, 2024).

2. Leverage Open-Source Collaboration for Business Scalability: Startups can use Open-Source collaboration to create solutions with other developers around the world, learn, and find strategic collaborations (Schneider et al., 2020; Hammad et al., 2023).

3. Integrate ROS into Cross-Industry Solutions: Companies ought to consider applying ROS outside of industrial robotics, where robots can be more efficient and new market segments can be introduced (Kendall and Park, 2023; Adeleke and Gyamfi, 2023).

4. Build Local ROS Communities and Developer Networks: Entrepreneurs need to establish or join local ROS user groups that are associated with universities and technology incubators. These types of networks result in increased knowledge exchange and local innovation ecosystems (Heinz et al., 2022; Hillali et al., 2025).

5. Align Business Models with Sustainability and SDGs: Since ROS has a chance of promoting environmental monitoring, precision farming, or health robotics, the startups should make their business models sustainable and aim at the opportunities of green finance and impact investments (Fang et al., 2025; Ross and Blumenstein, 2015).

5.3 Academic and Research Recommendations

1. Expand Empirical Studies on ROS Entrepreneurship in Africa: Future Research should empirically explore how ROS based startups are formed, run, and grow in the African settings. The field-based data on the connection between the adoption of ROS and the growth and creation of jobs in firms is insufficient (Adeleke and Gyamfi, 2023; Nawaz and Okafor, 2024).

2. Develop an Integrated Theoretical Model Combining RBV, TOE, and IDT: The researchers are supposed to transform the proposed conceptual model into quantifiable constructs. This integration will allow proving the mediating and moderating roles of digital preparedness, infrastructure, and policy on ROS-based entrepreneurship empirically (Aliyu Mohammed, 2024; Fang et al., 2025).

3. Promote University–Industry Collaborative Research: University institutions should join forces with robotics companies to engage in applied research of ROS implementation in terms of cost

reduction, localization, and indigenization (Hillali et al., 2025; Quigley et al., 2022).

4. Develop ROS-based Entrepreneurship Education Frameworks: Universities must incorporate hands-on ROS courses and open-source projects in the designs of the entrepreneurship curriculum, and students should be promoted to learn to employ the practical innovation skills (Hammad et al., 2023; Hillali et al., 2025).

Create Open Access Databases for ROS Innovation Research: Academic and policymakers ought to co-develop online databases of African ROS projects, patents, and start-ups. Such an open data project would enhance policy making based on evidence and assist the cooperation across the borders (Fukuda, 2020; Schlegel et al., 2022).

REFERENCES

1. **Abisoye, A., & Akerele, J. I.** (2022). A practical framework for advancing cybersecurity, artificial intelligence and technological ecosystems to support regional economic development and innovation. *International Journal of Multidisciplinary Research Growth & Evaluation*, 3(1), 700–713.
2. **Adeleke, T., & Gyamfi, D.** (2023). Digital capability and robotics entrepreneurship in Sub-Saharan Africa. *Journal of Innovation Studies*, 19(2), 55–70.
3. **Agarwal, N., & Brem, A.** (2015). Strategic business transformation through technology convergence: Implications from General Electric's industrial internet initiative. *International Journal of Technology Management*, 67(2–4), 196–214.
4. **Alabi, M.** (2025). Entrepreneurial ecosystems and the integration of technology for business success.
5. **Alka, T. A., Sreenivasan, A., & Suresh, M.** (2025). Entrepreneurial strategies for sustainable growth: A deep dive into cloud-native technology and its applications. *Future Business Journal*, 11(1), 14.
6. **Aliyu, M.** (2023, May 11). *An Agile Performance Management System for Achieving Sustainable Industry 4.0*. Paper presented at the One-Day Hybrid International Conference on Sustainability in Industry 4.0, MSNIM Manel Srinivas Nayak Institute of Management in association with Limkokwing University Malaysia.
7. **Aliyu, M.** (2023). *A Study on HR Strategies for Managing Talents in Global Perspective*. Paper submitted to the University of Belgrade, Technical Faculty in Bor, XIX International May Conference on Strategic Management (IMCSM23).
8. **Aliyu, M.** (2024). *Investigating Reskilling and Up-Skilling Efforts in the Information Technology and Software Development Sector: A Case Study of Kano State, Nigeria*. Paper presented at the *International Conference on Paradigm Shift Towards Sustainable Management & Digital Practices: Exploring Global Trends and Innovations*.
9. **Aliyu Mohammed.** (2023). *Navigating the digital marketplace: Strategies for entrepreneurship in electronic commerce*. *Computer Applications and Digital Innovation Journal*, 12(3), 44–59.
10. **Aliyu Mohammed.** (2024). *Entrepreneurial ecosystems and digital innovation strategies: Lessons from open-source development*. *International Journal of Technological Entrepreneurship*, 5(1), 77–96.
11. **Amar, A., & Abouabdellah, A.** (2016). Facility design and lean systems: Integrating spatial decisions with production strategy.
12. **Barney, J. B.** (1991). Firm resources and sustained competitive advantage. *Journal of Management*, 17(1), 99–120.
13. **Basole, R. C.** (2009). Visualization of inter-firm relations in a converging mobile ecosystem. *Journal of Information Technology*, 24(2), 144–159.
14. **Chan, C., Kim, J., & Park, Y.** (2020). Entrepreneurial performance and innovation ecosystems: A comparative global analysis. *Journal of Innovation & Entrepreneurship*, 9(3), 44–62.

15. **Chan, C. S. R., Patel, P. C., & Phan, P. H.** (2020). Do differences among accelerators explain differences in the performance of member ventures? *Strategic Entrepreneurship Journal*, 14(2), 224–239.
16. **Crnogaj, K., & Rus, M.** (2023). From start to scale: Navigating innovation, entrepreneurial ecosystem, and strategic evolution. *Administrative Sciences*, 13(12), 254.
17. **Cusumano, M. A.** (2008). The changing software business: Moving from products to services. *Computer*, 41(1), 20–27.
18. **Dresanala, P., Dewi, S., & Anwar, H.** (2022). Systematic approaches to qualitative conceptual analysis in management research. *Journal of Management Methodology*, 14(2), 77–95.
19. **Fang, C., Luo, Y., & Zhang, K.** (2025). Open innovation and entrepreneurship in digital ecosystems. *Entrepreneurship Review*, 16(2), 112–134.
20. **Fang, S., Li, X., & Huang, Q.** (2025). Open-source innovation and entrepreneurial collaboration in emerging markets. *Technovation*, 129, 103009.
21. **Fang, X., Tao, L., & Li, Z.** (2025). *AI Robotics Open Source R&D Survey: Foundation Models, Datasets, Simulation, and Benchmarks Platforms (2023–2025)*. Authorea Preprints.
22. **Fermin, S., Chung, P., & Li, J.** (2023). AI and robotics ecosystems: Emerging patterns in software-based entrepreneurship. *Technological Forecasting & Social Change*, 198, 122–139.
23. **Fukuda, K.** (2020). Science, technology and innovation ecosystem transformation toward Society 5.0. *International Journal of Production Economics*, 220, 107460.
24. **Guzman, J., Murray, F., Stern, S., & Williams, H.** (2024). Accelerating innovation ecosystems: The promise and challenges of regional innovation engines. *Entrepreneurship and Innovation Policy and the Economy*, 3(1), 9–75.
25. **Hammad, S., Patel, D., & Rehman, K.** (2023). Open collaboration and startup scalability in software ecosystems. *International Journal of Entrepreneurship & Management*, 12(4), 33–52.
26. **Hein, A., Schrieck, M., Riasanow, T., Setzke, D. S., Wiesche, M., Böhm, M., & Krcmar, H.** (2020). Digital platform ecosystems. *Electronic Markets*, 30(1), 87–98.
27. **Heinz, T., Wang, S., & Keller, P.** (2022). Innovation diffusion in open-source robotics communities. *Robotics and Computer-Integrated Manufacturing*, 78, 102417.
28. **Hillali, A., et al.** (2025). Cognitive frameworks in digital entrepreneurship education. *Entrepreneurship Education Review*, 17(1), 22–38.
29. **Hochberg, Y. V.** (2016). Accelerating entrepreneurs and ecosystems: The seed accelerator model. *Innovation Policy and the Economy*, 16(1), 25–51.
30. **Hu, M. K., & Kee, D. M. H.** (2022). SMEs and business sustainability: Achieving sustainable business growth in the new normal. In *Research Anthology on Business Continuity and Navigating Times of Crisis* (pp. 1036–1056). IGI Global.
31. **Janecký, D., Kučera, E., Haffner, O., Výchlopečná, E., & Rosinová, D.** (2024). Using Mixed Reality for Control and Monitoring of Robot Model Based on ROS 2. *Electronics*, 13(17).
32. **Janecký, J., Zdráhal, T., & Hnátek, L.** (2024). Mixed Reality HMI and Data Management in ROS 2: A Modular Open-Source Approach. *Applied Sciences*, 14(7), 3399. <https://doi.org/10.3390/app14073399>
33. **Juliano, D. R., Lima, C. S. C., & Doak, R.** (2025, April). Balancing early value creation with long-term R&D decisions: Lessons from robotics innovation. *Offshore Technology Conference* (p. D041S050R004). OTC.
34. **Kantis, H., & Federico, J.** (2020). A dynamic model of entrepreneurial ecosystems evolution. *Journal of Evolutionary Studies in Business*, 5(1), 182–220.
35. **Kendall, E., & Park, D.** (2023). Platform-based innovation models in robotics and automation. *Journal of Engineering Entrepreneurship*, 9(2), 61–79.

36. **Kolak, S., Afzal, A., Le Goues, C., Hilton, M., & Timperley, C. S.** (2020, September). It takes a village to build a robot: An empirical study of the ROS ecosystem. In *2020 IEEE International Conference on Software Maintenance and Evolution (ICSME)* (pp. 430–440). IEEE.
37. **Korreck, S.** (2019). The Indian startup ecosystem: Drivers, challenges and pillars of support. *ORF Occasional Paper*, 210, 193–211.
38. **Kumar, M. A., Mohammed, A., Raj, P., & Sundaravadivazhagan, B.** (2024). Entrepreneurial strategies for mitigating risks in smart manufacturing environments. In *Artificial Intelligence Solutions for Cyber-Physical Systems* (pp. 165–179). Auerbach Publications.
39. **Kwe, E.** (2024). Programming platforms for autonomous robotics: An overview of ROS-based innovations. *International Journal of Robotics Research*, 43(5), 211–225.
40. **Lawal, T. O., Abdulsalam, M., Mohammed, A., & Sundararajan, S.** (2023). Economic and environmental implications of sustainable agricultural practices in arid regions. *International Journal of Membrane Science and Technology*, 10(3), 3100–3114. <https://doi.org/10.15379/ijmst.v10i3.3027>
41. **Lepore, D., Micozzi, A., & Spigarelli, F.** (2021). Industry 4.0 accelerating sustainable manufacturing in the COVID-19 era. *Sustainability*, 13(5), 2670.
42. **Lienen, C.** (2023). Enabling reconfigurable hardware acceleration for ROS-based robotics applications. (Doctoral dissertation, Paderborn University).
43. **Lienen, J.** (2023). Open Robotics Software and Collaborative Innovation in Industry 5.0. *Robotics and Computer-Integrated Manufacturing*, 79, 102521.
44. **Macenski, S., Foote, T., Gerkey, B., Lalancette, C., & Woodall, W.** (2022). Robot Operating System 2: Design, architecture, and uses in the wild. *Science Robotics*, 7(66), eabm6074.
45. **Mason, C., & Brown, R.** (2014). Entrepreneurial ecosystems and growth-oriented entrepreneurship. *Final Report to OECD*, Paris, 30(1), 77–102.
46. **Mohammed, A.** (2023). *Analyzing global impacts and challenges in trade management: A multidisciplinary study. Economics, Commerce and Trade Management: An International Journal (ECTU)*, 3.
47. **Mohammed, A.** (2023). *Navigating the digital marketplace: Strategies for entrepreneurship in electronic commerce. Computer Applications: An International Journal (CAIJ)*, 10(3/4).*
48. **Mohammed, A.** (2023). *Strategic utilization of management information systems for efficient organizational management in the age of big data. Computer Applications: An International Journal (CAIJ)*, 10(3/4).*
49. **Mohammed, A., Jakada, M. B., & Lawal, T. O.** (2023). Examining the impact of managerial attitude on employee performance and organizational outcomes: A conceptual analysis. *International Journal of Business Review and Entrepreneurship*, 4(1), 1115–9146.
50. **Mohammed, A., Shanmugam, S., Subramani, S. K., & Pal, S. K.** (2024). Impact of strategic human resource management on mediating the relationship between entrepreneurial ventures and sustainable growth. *Serbian Journal of Management*. <https://doi.org/10.5937/IMCSM24044M>
51. **Mohammed, A., & Sundararajan, S.** (2023). Emerging trends of business transformation. *MSNIM Management Review*, 1, 36–44.
52. **Mohammed, A., & Sundararajan, S.** (2023). Exploring the dynamic interplay between startups and entrepreneurship: A conceptual analysis. In *Digital Startup: A Multidisciplinary Approach in Technology and Sustainable Development* (pp. 1–7). ISBN: 978-93-93376-66-4.
53. **Nawaz, A., & Okafor, E.** (2024). Policy and infrastructural readiness for robotics entrepreneurship in Africa. *African Journal of Technology Policy*, 6(3), 91–108.

54. **Padilla-Meléndez, A., Fuster, E., Lockett, N., & del-Aguila-Obra, A. R.** (2021). Knowledge spillovers, knowledge filters and entrepreneurial university ecosystems. *Knowledge Management Research & Practice*, 19(1), 94–105.
55. **Pugh, R., Soetanto, D., Jack, S. L., & Hamilton, E.** (2021). Developing local entrepreneurial ecosystems through integrated learning initiatives: The Lancaster case. *Small Business Economics*, 56(2), 833–847.
56. **Quigley, M., et al.** (2022). ROS: The open-source robotics middleware revisited. *IEEE Robotics & Automation Magazine*, 29(3), 21–33.
57. **Rogers, E. M.** (2003). *Diffusion of Innovations* (5th ed.). Free Press.
58. **Ross, P., & Blumenstein, M.** (2015). Cloud computing as a facilitator of SME entrepreneurship. *Technology Analysis & Strategic Management*, 27(1), 87–101.
59. **Roundy, P. T.** (2019). “It takes a village” to support entrepreneurship: intersecting economic and community dynamics in small-town entrepreneurial ecosystems. *International Entrepreneurship and Management Journal*, 15(4), 1443–1475.
60. **Sanil, H. S., Singh, D., Raj, K. B., Choubey, S., Bhasin, N. K. K., Yadav, R., & Gulati, K.** (2022). Role of machine learning in changing social and business ecosystems – A qualitative study. *World Journal of Engineering*, 19(2), 238–243.
61. **Schlegel, C., Haas, H., & Frenkel, K.** (2022). Ecosystemic perspectives in robotics software development. *Advanced Robotics*, 36(14), 741–753.
62. **Schneider, P., Boon, W., & Van den Bosch, F.** (2020). Digital ecosystems, open innovation, and entrepreneurship: A strategic integration model. *Journal of Business Research*, 112, 256–267.
63. **Schneider, S., Leyer, M., & Tate, M.** (2020). The transformational impact of blockchain technology on business models and ecosystems. *IEEE Transactions on Engineering Management*, 67(4), 1184–1195.
64. **Selander, L., Henfridsson, O., & Svahn, F.** (2010). Transforming ecosystem relationships in digital innovation.
65. **Shanmugam Sundararajan, S., Rajkumar, T., Senthil Kumar, T., Mohammed, A., & Prince Martin, V.** (2024). An analytical study on factors influencing individual investors’ decisions. *European Chemical Bulletin*, 12(1), 3706–3717. <https://doi.org/10.31838/ecb/2023.12.s1-B.372>
66. **Sundararajan, S., & Mohammed, A.** (2022). Entrepreneurial opportunities for women. In *Proceedings of the Conference on Gender Equality and Women Empowerment. European Journal of Humanities and Educational Advancements*, Special Issue, 45–57.
67. **Tausif, M., Sundararajan, S., Mohammed, A., Srinivasan, G., & Sundaravadivazhagan, B.** (2023). Industry 4.0 trends: Opportunities and challenges for new ventures. *Journal of Emerging Technologies and Innovative Research*, 10(2), 210–226.
68. **Tidd, J., & Bessant, J.** (2014). *Managing Innovation: Integrating Technological, Market and Organizational Change* (5th ed.). Wiley.
69. **Viktorov, V., & Khomenko, P.** (2021). Integrating robotics operating system (ROS) into entrepreneurship training: Opportunities for developing nations. *International Journal of Robotics Education*, 6(4), 122–139.
70. **Wade, M., & Nevo, S.** (2010). Development and validation of a perceptual model of IT-enabled business value. *Information Systems Research*, 21(4), 707–730.
71. **Wang, L., & Xu, X.** (2022). Interoperability and collaboration in ROS-based industrial automation. *Robotics and Computer-Integrated Manufacturing*, 77, 102358.
72. **Xu, X., Lu, Y., Vogel-Heuser, B., & Wang, L.** (2021). Industry 4.0 and ROS-based industrial automation: A review. *Engineering*, 7(12), 1756–1772.
- Yun, J. J., Zhao, X., & Park, K.** (2020). Open innovation and entrepreneurship: Linking dynamic

innovation systems with entrepreneurial ecosystems.

Sustainability, 12(10), 4058.