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The Future of Work

The Development of Sustainable Workplaces

Edited by Larisa Ivascu and Florin Dragan



The Future of Work - The Development of Sustainable Workplaces

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Aims and Scope of the Series

The social sciences, as a form of scientific knowledge anchored on epistemological foundations, theories, and specific methodologies, both in their fundamental and applied dimensions, are paramount for understanding and, consequently, developing instruments that contribute to improving social and environmental living conditions. This Social Sciences book series, based on the concept of the social sciences as key elements in the promotion of scientific knowledge and its inherent consequences, has as its primary goal to be a space for the dissemination of relevant information on various objects of study, aimed at specialists, students, policymakers, and others interested in the challenges facing humanity. Thus, the aim is to promote scientific progress through the sound and rigorous dissemination of studies that, from the perspective of the social sciences, either through a specialised disciplinary approach or through interdisciplinary perspectives, foster a deeper understanding of the objects under analysis, clarifying the issues addressed and their implications.

Meet the Series Editor



Dr. Sandro Serpa is an Associate Professor in the Department of Sociology at the University of the Azores (UAc), Portugal. His career in social sciences and education began at UAc in 2000. He earned his Ph.D. in Education, specializing in Sociology of Education, from UAc in 2013. He is also an integrated researcher at the Interdisciplinary Centre of Social Sciences of the Azores Centre (CICS. NOVA. UAçores). Dr. Serpa has demonstrated a strong commitment to higher education throughout his career. He has served in various positions at UAc, including Head of the Department of Sociology, Director of the Bachelor's in Social Work, Coordinator of the Scientific-Pedagogical Supervision Team for Social Work Internships, Member of the Pedagogical Council of the Faculty of Social and Human Sciences, and Member of the Quality Commission. Additionally, he held the position of Deputy Director of CICS. UAc. Currently, he serves as Senior Editor (Sociology Section) for Social Sciences & Humanities Open (Elsevier), among several other journals. He previously held the position of Senior Editor - Sociology Section for Cogent Social Sciences (Taylor & Francis) from 2020 to 2022. Dr. Serpa maintains a distinguished research profile, evidenced by over 400 publications in international journals, books, and other scientific outlets across a wide range of countries: Brazil, Canada, China, United Arab Emirates, Germany, India, Kazakhstan, the Netherlands, Pakistan, Poland, Portugal, Romania, Spain, Switzerland, Turkey, United Kingdom, United States of America. His research interests encompass Teaching Sociology, Sociology of Education, Sociology of Organisations, Organisational Culture, Scientific Communication, Digital Society, Digital Literacy, Society 5.0 and Sociology of Artificial Intelligence. Dr. Serpa emphasizes the importance of integrating academic knowledge with service to the university and society at large.

Meet the Volume Editor



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Professor Ivascu is the director of the Research Center for Engineering and Management, the president of the scientific committee of the Academy of Political Leadership, and vice-president of the Society for Ergonomics and Work Environment Management. She was the head of the Entrepreneurship Office of Politehnica University of Timisoara. She has extensive academic credentials, having published 11 books, 16 chapters in national and international books, and coordinated the editing of 12 books at internationally recognized publishing houses. Additionally, she has authored over 350 academic research studies and articles and is a member of international research bodies. She is a guest editor of prominent journals, a keynote speaker at various international and national events, a participant in national and international entrepreneur and academic projects, and a visiting professor at prestigious universities.



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2016). Dr. Florin Drăgan has extensive academic credentials, including seven published books and numerous academic research studies and articles. He is a key speaker at various international and national events and is part of national and international entrepreneur and academic projects. He serves as the guest editor of numerous publications and leads complex research teams. He is also involved in university management, developing strategies that contribute to enhancing the quality of the educational process and improving the university's international standing.

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Tradition and Innovation: Ecologies of Sustainable Learning in Contemporary Craft Work

by Andrey Felipe Sgorla, Claudio Melacarne and Claudia Banchetti

Preface

The Future of Work – The Development of Sustainable Workplaces is a comprehensive volume that explores the critical role of new challenges and technologies in the workplace.

The world of work is constantly changing. Advances in technology, automation, and artificial intelligence are contributing to this change, much like the mechanization of production and agricultural processes. This advancement will lead to the loss of some jobs, their elimination, and the creation of new jobs that require different skills and abilities. Events in the previous period have contributed to the reevaluation of specific processes and jobs. This volume highlights new perspectives and research on the future of work, workforce, and workplace. Artificial intelligence, technological advancements, social intelligence, new risks, and other aspects of sustainability and system engineering are approaches that require research and can contribute to the development of sustainable workplaces and increased organizational competitiveness.

The challenges of future jobs include automation and role transformation, labor market polarization, adaptability and continuous learning, ethics and trust in technology, reconfiguration of work processes, generative artificial intelligence (AI), and job sustainability.

Automation and role transformation are a challenge for both employees and employers. Skills will be transformed by artificial intelligence. Many workplace activities will require increasing interaction between humans and machines, and this dynamic will contribute to a substantial change in skills.

The polarization of work does not just mean the disappearance of some jobs, but a profound change in the social structure. Many of the projected jobs will no longer involve “working” but rather “designing, integrating, or guiding AI”.

Adaptability implies a high degree of flexibility. Employees must be able to reorient themselves quickly, acquire new skills, and learn throughout their lives. Future jobs will be increasingly unpredictable and with more uncertain variables.

Ethics is important in all workplace activities. When discussing the implications of this concept, transparency, safety, and fairness must be considered, as well as a balanced and responsible collaboration between humans and technology.

Reconfiguring the workplace is a crucial topic because AI-assisted hybrid work necessitates new models of management, productivity, and organizational culture. The future of work will not be “without people”, but with people augmented by AI.

Working with a physical presence in the office will gradually be replaced by flexible and collaborative models. Future work models will combine humanity with technology. All technologies must be adapted to the workplace and designed with appropriate dynamics.

Sustainable education and its underlying principles have clear implications for future job opportunities. These projections of new jobs will increasingly involve technology and the ability of employees to consolidate their new skills.

The book comprises several chapters, scholarly articles, and studies that examine contemporary issues related to sustainability, the impact of technology, and the future of labor. The book includes a series of research on sustainable education, the evolution of technologies and techniques in various fields of activity, as well as social aspects of changing the design of workplaces. These books address a wide range of subjects, including the use of AI in productivity, workplace safety, and organizational sustainability, as well as STEM education and workplace innovation. Many of them focus on how AI and digital transformation are altering the professional environment, while others examine the human and ethical implications of these changes. There are also works focused on education and sustainable practices, highlighting the importance of adapting and collaborating between tradition, innovation, and social responsibility. Overall, the volume reflects the primary research directions on transforming the workplace in the era of artificial intelligence and global sustainability. This volume brings together the latest approaches to work, aspects related to the future of work, workplace, workforce, and friendly and sustainable workplaces.

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Section 1

Strategies and Innovation

Future of Employee Workplace Engagement and Motivation: The Determinants of Organisational Performance in South Africa

Andrew Enaifoghe

Abstract

The chapter analyses the evolving dynamics of employee involvement in the workplace in South Africa, highlighting the intricate relationship between employment and motivation. South African organisations increasingly recognise employee engagement's critical importance in improving productivity, stimulating innovation, and attaining overall organisational success. Recent trends indicate that South African employees exhibit higher engagement levels than their global counterparts, with an engagement rate of 29%, surpassing the global average. Key factors influencing this positive trend include robust labour rights, effective management practices, and comprehensive employee engagement programmes. These programmes frequently encompass performance assessments, coaching, and work-life balance initiatives, enhancing job satisfaction and motivation. The research examines the impact of corporate culture, skills enhancement, and organisational environment on employee motivation and job satisfaction. This study uses qualitative and quantitative research methodologies to identify the elements affecting employee engagement and propose strategies for sustaining high motivation levels. The results demonstrate that an engaged workforce improves organisational performance and fosters a positive work environment, reducing turnover and boosting employee well-being.

Keywords: employee workplace, engagement, organisational performance, motivation, corporate culture

1. Introduction

In the dynamic and growing corporate environment of South Africa, employee engagement and motivation are essential factors influencing organisational performance. This chapter examines future trends and techniques that South African organisations might utilise to improve employee engagement and motivation, thereby enhancing performance. Utilising data analytics to comprehend employee

preferences, actions, and performance will allow firms to customise their engagement tactics [1]. Scholars believe that adopting data-driven decision-making guarantees that initiatives correspond with employee requirements, improving overall engagement and organisational efficacy [2].

Technology innovations, flexible work structures, wellness programmes, competent leadership, and data-informed strategies influence the future of employee engagement and motivation in South Africa. By concentrating on these domains, South African firms may cultivate a flourishing work environment that enhances outstanding performance and fosters sustainable growth.

Employee engagement in the workplace has become a crucial determinant of organisational performance, affecting productivity, innovation, and overall employee well-being [3]. In South Africa, the dynamics of employment and motivation are experiencing substantial modifications due to socio-economic developments, technological breakthroughs, and shifting corporate cultures [4]. This study examines the future of employee workplace engagement, emphasising the correlation between employment and motivation in chosen organisations in South Africa.

This study seeks to investigate these dynamics using both qualitative and quantitative research methodologies, offering insights into the factors influencing employee engagement and recommending practical ways for organisations to maintain elevated levels of motivation. By comprehending the complex interplay between employment and Motivation, South African organisations may more effectively address the problems and possibilities of the future, so securing sustainable growth and competitive advantage.

2. Literature consideration

South African organisations progressively emphasise employee engagement as a strategic necessity [5]. This transition is evident in several programmes designed to augment worker happiness, cultivate a good workplace atmosphere, and encourage a culture of ongoing enhancement. The relationship between employment circumstances and motivating factors is intricate, encompassing job stability, professional advancement chances, and recognition initiatives [6].

The use of new engagement initiatives, such as flexible work arrangements, comprehensive wellness programmes, and effective performance management systems, has demonstrated favourable outcomes in enhancing employee morale and commitment [6, 7]. Moreover, South Africa's peculiar socio-cultural environment, marked by variety and resilience, contributes a unique aspect to the engagement landscape.

Employees are essential to the success of any organisation. Their abilities and competency are essential for the organisation's performance [3]. A conducive working environment is vital for the organisation's survival in this competitive landscape [8]. Furthermore, it is unequivocal that the aims and objectives of an organisation can only be achieved by efficiently utilising additional resources, including human capital [3]. The South African government is now facing several challenges in delivering public services. The government's failure to enhance service delivery may lead to large demonstrations in South Africa [9].

Notwithstanding several advancements, the public sector in South Africa persists in operating inadequately. Scholars assert that employee contributions are vital in determining an organisation's success or failure [1, 10]. Protests and discontent have emerged in South African communities owing to the government's unfulfilled

promises and delays in delivering essential services [11]. This is a legitimate issue as South Africa, like several other developing nations, possesses a troublesome public sector, and public sector reforms have been predominantly unsuccessful [7].

Consequently, as previously said, employee involvement is vital for an organisation's success [12]. Success in the contemporary competitive workplace is contingent upon robust employment connections, while work engagement can facilitate an effective performance management system. Consequently, programmes focused on enhancing quality are increasingly gaining recognition and acceptance [3]. Contemporary businesses, in a climate of widespread expansion, must prioritise and need employee performance that aligns with organisational objectives [13]. Organisations often endeavour to attain goals, objectives, and targets over time or within a designated timeframe [11].

Nduati and Wanyoike [14] assert that an organisation may enhance its capacity to achieve long-term objectives by using performance management methods that encourage and inspire personnel. Numerous aspects must be considered to improve performance management systems in the public sector [15]. This is essential as integral systems, such as performance management systems, influence performance [10]. Furthermore, organisations are recognising the necessity of efficient performance management systems to guarantee stability and success in today's increasingly competitive markets; thus, there has been a rise in interest in implementing such systems [10].

Furthermore, the human resources (HR) department is integral to the performance management system, which aims to assess workers' overall performance [5]. Human Resource managers in every organisation are tasked with overseeing and regulating employee performance [14]. Lakshmi and Sireesha [16] assert that organisations aiming to promote employee performance must educate themselves on potential aspects that might facilitate improved performance. The primary factors affecting employee performance are the efficacy of the performance management system, the nature of connections between employees and employers, and the degree of job engagement.

Organisations necessitate motivated and engaged personnel, as their success is contingent upon them [13]. Therefore, enhancing work engagement has emerged as a crucial element for organisations [17]. South African law acknowledges the significance of work interactions [13]. Robust working relationships are founded on transparent communication between employees and employers [18]. Targets are subjected to continuous pressure to achieve elevated performance standards and guarantee their work aligns with the organisation's objectives [16]. This study examines performance management systems [19], work engagement [20], and employment relationships [21] as evaluative tools.

Consequently, these instruments are employed to examine whether employment connections and job engagement affect or forecast the performance management systems in South Africa's public sector. No comparable study was identified in the literature that examined whether employment relationships and performance management methods forecast work engagement. This research addresses this gap in the literature [22].

3. Employee engagement in South Africa

Employee engagement has emerged as a pivotal concern for organisations globally, including those in South Africa. Studies demonstrate that engaged employees exhibit

higher productivity, innovation, and organisational commitment. Factors influencing employee engagement in South Africa encompass job resources, organisational support, and possibilities for progress. Ngwane and Dachapalli's [23] personal engagement model and Schaufeli et al.'s [24] job engagement model emphasise psychological meaningfulness and availability as primary determinants of engagement.

Research in South Africa shows that various industries and organisations have differing degrees of employee involvement, which is a matter of continuous controversy. Some research indicates a high degree of involvement, especially when compared to worldwide norms, while other data shows worryingly low-interest levels [25]. Crucial factors for increasing employee engagement in South Africa are excellent leadership, a caring culture, and meaningful employment. The ability to swiftly and effectively implement business and personnel strategies is a key differentiator for high-performing firms.

Since the 2008 financial and economic crisis, the world economy has changed [26]. Hill [27] acknowledged that administrative and regulatory hurdles are reducing, making it easier to do business abroad. As a result, businesses large and small, from developed to developing economies, are able to expand internationally. With the rise of globalisation, big data, the Internet of Things, and other technological advancements, companies can no longer differentiate themselves from one another beyond their personnel.

A key finding of Van der Walt's research is the need to maintain high performance to gain a competitive edge in a more unstable economic climate [28, 29]. An integral part of any successful management strategy is performance management. Its purpose is to measure the attainment of predetermined key performance indicators (KPIs), foster talent growth, establish core competencies, and improve employees' skill sets, all of which contribute to the company's sustained success [23]:

"...A successful management strategy is performance management is a continual process of identifying, measuring and developing the performance of individuals and teams and aligning performance with the strategic goals of the organisation ([23], p. 2).

Research has shown that performance management can backfire if the goals of an organisation are not in line with the metrics used to evaluate its success [4]. In today's business world, the performance of one's employees is one's primary competitive edge. According to Ali et al. [30], employee engagement has been touted as a cornerstone of a company's success and has been more popular in recent years. It would appear that executives are quickly realising the link between invested workers and prosperous companies:

"...The importance of employee engagement to commercial and business performance is being recognised more and more" ([27], p. 2).

Employee engagement is no longer a luxury; it is a must for companies who wish to beat their rivals. Employee engagement has transitioned from a discretionary aspect of corporate strategy to a vital component for organisations pursuing competitive advantage and success. Engaged personnel exhibit heightened productivity, innovation, and loyalty, resulting in enhanced customer happiness, augmented profitability, and fortified brand loyalty. A company's performance is fundamentally connected to the degree of involvement of its personnel.

3.1 Performance oversight and engagement

Performance management is intricately connected to employee engagement. Efficient performance management systems may improve engagement by establishing clear expectations, offering consistent feedback, and facilitating development opportunities. Research in South Africa indicates that organisations with effective performance management methods generally exhibit elevated levels of employee engagement. This link highlights the necessity of synchronising performance management techniques with engagement activities to enhance organisational efficiency and effectiveness:

“Performance management is an ongoing process of identifying, measuring, and developing the performance of individuals and teams and aligning performance with the organisation’s strategic goals” ([31], p. 2).

The first of Aguinis’s two important considerations for organisations is that it is a “continuous process,” meaning that it is continuing. Many companies mistakenly believe that conducting performance assessments on a biannual basis constitutes performance management. Managers and HR business partners’ lack of comprehension is evident here. In most cases, managers view performance evaluations as little more than a formality enforced by HR [32]. Second, “aligning performance with the strategic goals” is important because when a company’s demands change, so too do employees’ ambitions [33].

Performance management differs from performance evaluation. When it comes to the difference between performance assessments and performance management, it is important to reach the same conclusion [30, 34, 35]. In a performance review, according to Aguinis, goals for an employee’s contributions are not clearly defined, and the evaluation occurs once or twice a year without ongoing coaching and feedback. Performance evaluation is a component of performance management. Furthermore, they both agree that performance management is best understood as an ongoing process rather than a predetermined series of events. Inspiring workers to up their game is the main goal of these events.

3.2 Employment and motivation

The connection between job and motivation is complex, encompassing several organisational and individual aspects. Opportunities for training and professional advancement substantially influence employee motivation and emotional commitment [36, 37]. Employees who regard their positions as secure and identify distinct opportunities for professional progression are more inclined to exhibit motivation and engagement. The establishment of employment equality rules has been demonstrated to enhance employee motivation by promoting a sense of justice and inclusion.

3.3 Case analyses and practical consequences

Numerous case studies from South African organisations offer insights into effective engagement techniques. The Umhlathuze Valley Sugar (UVS) case study illustrates the influence of employee engagement on organisational productivity. Identified key tactics are cultivating a culture of involvement, implementing effective leadership, and enhancing communication. These case studies indicate that

customised engagement initiatives may improve employee motivation and organisational performance.

The literature about employee workplace engagement in South Africa emphasises the significance of strategic initiatives that link job circumstances with motivating elements. Organisations may cultivate a highly engaged and motivated staff by utilising performance management, training, career development, and equitable employment policies [36, 38]. This can, thus, foster sustained growth and competitive advantage in the evolving South African market.

4. Research methodology

4.1 Research design

The study used a qualitative approach and a cross-sectional research design technique to investigate a topic. It took into account interview data from 10 South African employees and was based on a literature analysis on performance management and employee engagement.

Since the research design specifies the steps to take and the data to gather, it is essential to pick a legitimate and suitable design to get trustworthy results [33, 39]. Research design is the methodical framework for gathering data. This study used a correlation design because the researcher was interested in the connection between work motivation and employee engagement.

4.2 Qualitative approach

The study adopted qualitative research approach. Understanding the “why” and “how” of social phenomena is the main goal of qualitative research, which examines rich, descriptive data such as words, behaviors, and feelings. It involves getting a deep understanding of people’s viewpoints and experiences, frequently through focus groups, observations, and interviews.

4.3 Sampling technique and population

The organisation had been running in South Africa for 50 years, and at the time of the research, it had a staff of around 140 people, including 60 full-time employees and 80 temporary workers. When conducting a study, employing a subset of the target population rather than the entire population at random is common practice. This type of sampling is known as non-probability convenience sampling [40].

The researchers utilised a non-probability convenience sample because the study was exploratory and wanted to find out what workers thought at various levels of the company. This was because personnel were readily available and researchers were able to accommodate their schedules by allowing them to participate in the study during company hours.

Ten workers from different departments and levels of the company’s operations were chosen for the sample; they all participated in employee engagement activities and were part of the performance management process. Men made up the bulk of the participants (60%). Concerning racial composition, 60% were Black, 30% were Indian, 5% were White, and 5% were of Coloured race. To ensure their privacy, each participant was given a code ranging from P01 to P10.

4.4 Research tool

Researchers should use open-ended inquiries because they encourage participants to speak their minds without fear of reprimand [41]. Researchers were able to employ semi-structured interviews with participants who were guided by an open-ended discussion guide since the study was exploratory in nature. This allowed the researcher to give all participants identical open-ended questions, allowing them to expound and provide more detailed answers. The researcher could stay on track to examine the study's objectives while probing for further clarity and comprehension. One problem with this kind of instrument is how long it takes to complete the steps involved in using it, from conducting individual interviews to coding and transcribing the results.

4.5 Interview

The interview procedure was designed to be as easy as possible for participants so they may easily refuse or end their involvement at any point. All participants were required to have a high school diploma or equivalent, 1 year of work experience, proficiency in English, and to have been involved in performance management in some capacity.

4.6 Data collection

In order to gather information for the study, the researcher reviewed relevant web papers from reputable South African and worldwide journals to learn about academic perspectives on performance management and employee engagement. In light of this information, the researcher developed an interview guide to help participants share their thoughts on employee engagement and performance management. Because of the use of semi-structured interview questions and subsequent free-flowing conversation, participants' opinions and ideas were able to shine through.

During regular business hours, participants were interviewed at the organisation's location at times that were convenient for them and did not disrupt activities. All participants were asked to provide constructive criticism objectively. The duration of each interview ranged from 30 to 45 minutes, and participants were encouraged to give more details and examples to help the interviewer grasp and record their ideas accurately. Once the interviews are over, the researcher might follow up with participants by phone or in-person meetings to see if they need more information on their answers. This was based on the participants' availability.

4.7 Analysing data

After each interview, the researcher reviewed the notes and recordings to ensure she understood the participants' answers; if more clarification was needed, the participants were contacted as soon as it was convenient. After conducting a first read-through of the data to become acquainted with it, the researcher encountered data saturation after 10 interviews; no additional codes or themes emerged. The next step in data analysis was to transcribing the participant's answers into a separate Microsoft Excel spreadsheet for each question.

Capturing and organising qualitative data requires the ability to "see" and assign tags or codes to represent or infer information obtained throughout the investigation. Paragraphs, sentences, or even individual words might be given a code [13]. Next, I coded the responses based on our analysis of each question's essential terms

and phrases. After each question was posed, the highlighted codes and words were combined into a single data set.

4.8 Trustworthiness and veracity

Researchers doing qualitative research have the burden of demonstrating the study's credibility through a validity approach, notwithstanding the difficulty of conceptualising validity in this type of research [42]. According to Creswell and Miller, validity is the degree to which the participants' beliefs and perspectives on the phenomenon have been taken into consideration in a credible and correct manner. The study relied on the extensive, comprehensive description to establish credibility, but other validity approaches are available. The goal was to make the readers feel as though they were there in the interview and to let them "see" the feelings conveyed *via* the words.

4.9 Ethical consideration

The researcher had to get approval from the Ethical Committee. The study was to adhere to the following principles: The researcher sought approval to conduct the study in the selected organisation by drafting a Memo to the organisation seeking permission to collect the data. The approved Memo was included in the Ethics application. Ethical clearance was obtained from the Ethics Committee at the University of Zululand, and informed consent was given to the participant to ensure that they understood their voluntary involvement in the study during the data collection process.

5. Demographic profile and distribution of the participants

This section summarises the conclusions reached about the respondents' demographic profile. It provided the gender, age, education level, employment division and employment type of the employees in the selected organisation, which are essential factors in this section (**Table 1**).

Code	Gender	Race	Age	Education	Position
P01	Male	Black	46	Master	Manager
P02	Male	Black	38	B.Sc	Support Services
P03	Male	White	40	B.Sc	Management
P04	Male	India	37	Honours	Marketing
P05	Male	Coloured	29	Diploma	Customer Relations
P06	Male	Black	33	B.Sc	Customer Relations
P07	Female	Black	35	Honours	Corporate Affairs
P08	Female	Black	31	B.Sc	Corporate Affairs
P09	Female	Indian	32	B.Sc	Support Services
P10	Female	Coloured	32	Master	Management

Source: Author's compilation (2025).

Table 1.
Demographic profile and distribution of the respondents.

6. Results and discussion of research findings

6.1 Work engagement and employee performance

This section of the study explored the understanding of employee engagement as the “harnessing of the members of an organisation to their work roles”. In engagement, people employ and express themselves physically, cognitively, emotionally, and mentally during role performances. Physical, emotional, and cognitive engagement are three components of work motivation. There are two schools of thought for defining job engagement. If an organisation does not have an employee engagement technique, it is challenging to create a team of motivated co-workers to give their best work. The study examined the future of employee workplace engagement and motivation to determine South Africa’s organisational performance.

Research question 1:

What is the relationship between employment and motivation for organisational performance in your organisation?

Responses:

“...At our organisation, job security plays a crucial role in motivation. Knowing that our positions are stable allows us to focus on our work and strive for excellence without fearing losing our jobs” (P01).

“...Career development opportunities are a significant motivator. Our organisation invests in training and development programs, which help us grow professionally and stay motivated” (P02).

“...Recognition and rewards are key to maintaining high motivation levels. When our efforts are acknowledged, it boosts our morale and encourages us to continue performing well” (P03).

“...A positive work environment is essential. Our organisation fosters collaboration and support, making us feel valued and motivated to contribute our best” (P04).

“...Flexibility in work arrangements, such as remote work options and flexible hours, greatly enhances our motivation. It allows us to balance our personal and professional lives effectively” (P05).

“...Effective leadership is a major factor. Leaders who inspire and support us create a motivating atmosphere where we feel empowered to achieve our goals” (P06).

“...Clear communication of goals and expectations helps us stay motivated. When we understand what is expected of us, we can align our efforts and work towards achieving those objectives” (P07).

“...The sense of purpose and meaningful work drives our motivation. Knowing that our work makes a difference and contributes to the organisation’s success keeps us engaged” (P08).

“...Team dynamics and strong interpersonal relationships are crucial. Working with supportive colleagues in a cohesive team environment boosts our motivation” (P09).

“...Access to necessary resources and tools is vital. When we have what we need to perform our jobs efficiently, it reduces frustration and enhances our motivation” (P10).

The study attempts to draw a connection between engagement and motivation. It was noted that employees who are motivated by internal factors are often engaged. They are passionate about using their talents, work hard to learn new skills, and love what they do. Additionally, much must be written about how an engaged staff may improve any company's bottom line. According to Aberdeen Group, having engaged staff boosts income by 26% annually and customer loyalty by 233%. On the other hand, if your staff members are intrinsically motivated, they probably require continual encouragement to produce. This strategy might be effective in the short term but cannot last. Not every work or project is eligible for payment or benefits.

Additionally, if a worker's only source of incentive is fear-based, such as the dread of being disregarded, they may easily burn out if their management fires them or they lose their jobs. In that instance, what is left is a collection of disillusioned, disengaged workers who also have the potential to harm the bottom line. In fact, according to the Harvard Business Review, even one of them can run a business for about R12,000 a year. Employees may be innately motivated, but it does not mean they do not need extrinsic rewards to keep them going.

They have already completed the task when the reward arrives, as opposed to needing the reward to complete the task, which prevents it from making them extrinsically motivated. The study also found that bonuses, honours, or even a heartfelt “thank you” can be used as a form of recognition. Enthusiastic employees will work harder and perform better for years if management expresses appreciation for their wonderful work. Employee engagement is essential to competitive success, and intrinsic motivation plays a significant role in this dynamic. Fortunately, with the correct approach, inspiring your team to passionate productivity is feasible. You will realise that attempting to separate them is a delusion.

6.2 Employee motivation increases organisational performance

Findings show that employers value their employees' lives more. According to how they rank their present and future lives on a ladder scale with steps numbered from 0 to 10, based on the Cantril Self-Anchoring Striving Scale, Gallup categorises people as “thriving,” “struggling,” or “suffering.” Sufferers are those who give both their current and future life a rating of seven or lower. Those who give their current and future life a rating of seven or higher are considered to be thriving. The study discovered that true potential can only be unlocked and realised through motivation, yet each person has different motivational triggers.

Research question 2:

How can you foster an environment at work where everyone feels inspired and motivated?

Responses:

“...Create a culture where employees feel comfortable sharing their ideas, concerns, and feedback. Regularly hold team meetings and one-on-one sessions to facilitate open dialogue” (P01).

“...Acknowledge employees' hard work and accomplishments through awards, bonuses, or simple verbal praise. Recognition can significantly boost morale and motivation” (P02).

“...Offer training programs, workshops, and career development opportunities. Employees who see a clear path for advancement are more likely to stay motivated” (P03).

“...Promote a friendly and inclusive workplace culture. Encourage teamwork, celebrate diversity, and ensure that everyone feels valued and respected” (P04).

“...Clearly define roles, responsibilities, and objectives. When employees understand what is expected of them, they can focus their efforts more effectively” (P05).

“...Implement policies that support flexible working hours, remote work options, and adequate time off. A balanced work-life can lead to higher job satisfaction and motivation” (P06).

“...Ensure that employees have the tools, technology, and support they need to perform their jobs efficiently. This can reduce frustration and increase productivity” (P07).

“...Create an environment where creativity and new ideas are welcomed. Encourage employees to take risks and experiment without fear of failure” (P08).

“...Demonstrate the values and behaviors you want to see in your team. A motivated leader can inspire and motivate their employees” (P09).

“...Foster strong interpersonal relationships within the team. Organise team-building activities and social events to strengthen bonds and create a sense of community” (P10).

According to the survey findings, those who enjoy their jobs are more likely to flourish in their personal lives globally. In actuality, only a few of the employees who enjoy their jobs think their lives are generally good. There is a 16 percentage point difference between the lives of the people who enjoy their jobs and the lives of the other 21% of workers, who do not enjoy their jobs. Contrarily, employees who do not enjoy their jobs are twice as likely to be in pain as employees who do. This discrepancy demonstrates how crucial it is for people to take pleasure in their profession. We must support our staff members' curiosity and willingness to question the current status quo. Employers should also put much effort into creating a culture of openness and trust that encourages our workers to take risks with one another and their ideas.

6.3 Extrinsic motivation on employee engagement

The study noted that extrinsic motivation is a type of drive that is fuelled by benefits from outside sources. These can be material, like cash or grades, or immaterial, like acclaim or renown. Extrinsic motivation is solely focused on external rewards, in contrast to intrinsic motivation, which comes from within the person. Extrinsically motivated individuals will keep at a task even if it is not delightful in and of itself. For instance, someone might perform a task at work that they dislike in order to pay their bills.

Findings show that operant conditioning involves extrinsic incentives in which a person or item is trained to perform in a certain manner in exchange for

a reward or punishment. The over justification effect refers to the propensity of extrinsic drive to undermine intrinsic motivation. This entails a decline in actions driven by internal motivation following the cessation of external reinforcement for the behaviour.

Research question 3:

Why can rewarding behaviour or performance that is already intrinsically rewarding cause this sudden lack of interest?

Responses:

“...When external rewards are introduced, they can shift the focus from the intrinsic enjoyment of the task to the reward itself. This can diminish the internal motivation that originally drove the behavior” (P01).

“...Receiving external rewards can create a dependency on those rewards. Once the rewards are removed or reduced, the intrinsic motivation may not be strong enough to sustain the behavior” (P02).

“...External rewards can sometimes feel like a form of control or manipulation, which can lead to resistance and a decrease in intrinsic motivation” (P03).

“...The introduction of rewards can change the perception of the task from something enjoyable to something that is done for the sake of the reward. This shift can reduce the natural interest in the activity” (P04).

“...When behavior is rewarded externally, it can undermine the sense of autonomy and self-determination, which are key components of intrinsic motivation” (P05).

“...External rewards can create pressure and expectations, which can lead to stress and reduce the enjoyment of the task” (P06).

“...The novelty of the external reward can wear off over time, leading to a decrease in motivation once the reward is no longer seen as exciting or valuable” (P07).

“...Intrinsic motivation is often driven by personal values and interests. External rewards can distract from these internal drivers, causing a loss of interest” (P08).

“...When external rewards are given for intrinsically rewarding tasks, it can lead to a feeling that the task is being done for the wrong reasons, which can reduce motivation” (P09).

“...External rewards can sometimes lead to a focus on short-term gains rather than long-term satisfaction, which can diminish the intrinsic enjoyment of the task” (P10).

One explanation to the research findings is the propensity of people to consider why they are doing something. Once they have received an external incentive for conduct, they overvalue the reward's role in shaping their behaviour [43]. Another reason is that when activities are attached to obligations, they might go from fun or play to work. Extrinsic rewards for employees can be a powerful tool for behaviour modification and impact employee performance at the workplace.

Experts caution that they should only be used sparingly, especially with young people [28]. More research is required to pinpoint precisely how and when external rewards may diminish intrinsic drive. Extrinsic rewards can potentially be beneficial and largely successful for learning [42].

7. Conclusion on finding

The findings show the need for employees to be motivated to accomplish organisational goals after being hired, receiving proper training, and starting their jobs. Given the company’s regulations and policies, companies that try to develop an appropriate remuneration package attempt to recognise employees’ intrinsic and extrinsic demands. However, businesses must make an effort to be understanding with their workers while keeping in mind their strategic objectives.

The primary problem stems from the misalignment of organisational objectives and employee requirements. In the subject of organisational behaviour, where there are no certain, absolute motivators, the word “employee motivation” is dynamic. Indeed, for many academics and businesses around the world, the idea of “employee motivation” continues to be one of the most difficult and contentious ideas.

7.1 Employee engagement at the workplace

Findings in the study show that the relationship between organisations and their employees is characterised by employee engagement. Employee commitment and

Pride in the company	Workers who share the company’s values are more likely to be committed to it and serve as brand ambassadors.
Leadership	Participation begins at the top. Employees are motivated to contribute to the group goal when leaders are present and actively involved in everyday activities.
Engagement	Management style greatly influences engagement, namely how managers and employees relate. To keep their workforce interested, managers must offer support and direction.
Opportunities for advancement	When employees can see their route to advancement, investing in the company and themselves are identical.
Resources	Engagement rises when workers are provided the tools they need to execute their jobs.
Autonomy	Employees are free to operate independently when their roles and success criteria are clearly defined, increasing their sense of job satisfaction.
Employee commitment	Employee commitment is higher when companies support their staff members’ physical and mental health and a healthy balance between their personal and professional lives.
Office culture	When co-workers become close friends, employees develop stronger bonds with their company as a whole, and engagement rises when there is a true feeling of community in the workplace.
Diversity	There is a high correlation between diversity and employee engagement, which suggests that diverse teams are more devoted and collaborative.

Source: Author’s compilation (2025).

Table 2.
Employee experience and viewpoint elements.

passion to the business, its core principles, and its mission are measured by engagement metrics. Employee engagement was first used in the early 1990s by organisational behaviour professor William Kahn, and it is now widely used by businesses, who have included it into their HR programmes and overall business strategy. In line with Khan, this study's findings shows that engagement is measured using a variety of employee experience and viewpoint elements, such as (**Table 2**):

Accordingly, employee engagement rises when workers are provided the tools to execute their jobs. Employee commitment remains high when companies support their staff members' physical and mental health and a healthy balance between their personal and professional lives. This suggests that employees are more likely to feel happy to work for an inclusive firm. Employee engagement boosts productivity, lowers attrition, and results in even fewer workplace errors and accidents. On the other hand, disengaged workers can cost national economies billions of dollars annually.

7.2 Employee motivation factors

The findings according to Sabbagha et al. [42], three factors define employee efforts: the direction of the efforts (choosing among various alternatives to achieve goals), the strength of the efforts (the degree of commitment with which employees pursue the preferred alternative), and the persistency of the efforts (preserving behaviour). The inner and extrinsic elements that affect employee motivation are the two most crucial parts of this concept when addressing it.

Intrinsic or internal elements that affect employees' motivation are those internal forces that propel individuals to complete a task flawlessly. Extrinsic Motivation, on the other hand, is described as "employees who are externally motivated by a materialistic reward (usually financially) such as pay, promotion, praise, or avoidance of any negative consequences". Extrinsic motivation comes from outside sources (like employers), but internal motivation comes from within the individual employees.

Okoth and Florah [43] explored several factors for employee motivation in their study, including "salaries and benefits, employee recognition, job satisfaction and job security, as well as training and development". These factors may be the key to motivating employees to work harder. Employee motivation differs from person to person and is affected by various motivational factors. This is because each employee has a distinct personality and character, everyone comes from a different cultural background, and there are generational differences among employees within the same firm.

As a result, companies need to be able to encourage employees with diverse backgrounds and traits to work harder. Employees who are content with their jobs are highly driven, devoted to their employers, and passionate about making a positive difference in how well those employers operate. Numerous factors affect employee performance, but technological development and globalisation dominate because they give credit for intellectual abilities instead of physical labour.

7.3 Companies work hard to develop ways to inspire their staff

To learn what can spur employees to work more, numerous studies have been conducted in this manner. However, a lot of businesses use incentives to spur on their workers. Companies established organisational awards to encourage employees to perform more and meet additional company strategic goals. Incredibly, "previous psychology research papers claim that non-monetary rewards exert greater outcomes

on employee motivation” [44]. There are two different types of rewards: monetary rewards and non-monetary rewards.

Non-monetary benefits also aid in reducing any stress that workers may experience at work, and they may also boost employees’ self-confidence, which could have an immediate impact on the competitiveness and profitability of the companies where they are working. On the other hand, “monetary rewards usually decrease teamwork performance as employees focus primarily on individual cash gains”. However, in the study conducted by [45] noted that prior studies showed that not all monetary awards may positively impact employee motivation.

Amazingly, even when two employees work for the same organisation, one non-cash gift may be able to motivate one while failing to motivate the other. This is because each employee has a preferred type of motivation. For instance, some employees may have higher self-esteem if they are promoted or given additional responsibilities at work thanks to their favourable performance in the past. While other workers could become disengaged and exhausted as a result of their increased obligations and accountability following a promotion. The study covered a number of factors that influence employee motivation. However, a lot of scholars have neglected to look at how giving employees a mix of monetary and non-monetary benefits affects them.

To put it another way, would employees be motivated if they received a promotion to a higher-level position and a one-week paid vacation at the same time? Most scholars contrasted the value of monetary rewards versus non-monetary benefits in their discussions. But if academics thoroughly examine the impact of supplying a mix of monetary and non-financial incentives, the field of human resources might benefit greatly a non-monetary reward to employees.

7.4 Essential elements that affect job satisfaction

7.4.1 The corporate environmentalism and people’s mindsets

The corporate ecology and people’s mindsets can impact employee happiness and the organisational ecosystem. Firstly, the organisation’s goal must be to motivate employees if you want to maximise employee happiness. They will learn through this how they contribute to making the world a better place. But having a goal alone is insufficient; we also need conscientious leaders who can establish all the circumstances for their team’s success while fostering inclusive, collaborative cultures with high levels of personal liberty, psychological safety, and openness. The development and well-being of the workforce must also be a major priority for leaders.

These are all characteristics of conscious, forward-thinking businesses that improve employee happiness while improving the world. This kind of company is well represented by Patagonia, which is also a B corp, which calls for a highly stringent certification procedure. These businesses’ mission statements are predicated on their capacity to have a beneficial influence on their workforce, the neighbourhood, and the environment.

7.4.2 The significance of employees’ mental health

On the significance of employees’ mental health. According to Sonia Lyubomirsky’s research, 40% of our happiness is dictated by our attitudes, 10% by

our life circumstances, and 50% of it is determined by our genes. Therefore, a big part of pleasure is how we respond to things, and that is something we can all influence. An employee with a terrible attitude may therefore be miserable at work, even in a great setting with all of the qualities mentioned above, unless they decide to alter their attitude and adopt a positive mindset filled with gratitude and compassion.

7.4.3 Personal income goals

Findings show how important it is to set objectives that can be an effective strategy for fostering personal and professional growth. Setting life goals for yourself eventually means approaching accomplishment with an open mind and moving closer to your career objectives. One can start by establishing some short-term objectives, which can then be utilised as a springboard to larger, longer-term objectives [46]. What must you do to reach your earning goals? This is a challenging subject because, to be honest, a lot of the conversation makes it sound simpler than it is.

To check that the math is correct, we must look at the products, programmes, or services you are providing, the price point of each offer, and the quantity of sales required at each price point in order to meet your income target. Many coaches today advise people to launch their businesses by providing a low-cost product or offer. The idea is to gradually raise the price point on several products or programmes over time. We refer to this as an ascension model.

7.5 Concluding remarks

The study noted that South African organisations are increasingly prioritising employee engagement as a strategic need. The transformation is apparent in several initiatives aimed at enhancing employee satisfaction, fostering a positive work environment, and promoting a culture of continuous improvement. The connection between employment conditions and motivational variables is complex, involving aspects such as job security, opportunities for career progression, and recognition programmes.

Implementing innovative engagement strategies, including flexible work arrangements, extensive wellness programmes, and efficient performance management systems, has shown positive results in improving employee morale and commitment [7, 47, 48]. Furthermore, the distinctive socio-cultural milieu of South Africa, characterised by diversity and resilience, adds a singular dimension to the engagement landscape.

In summary, the future of employee workplace engagement in South Africa is optimistic, with an increasing focus on fostering supportive and encouraging work environments. By comprehending and using the correlation between employment and motivation, organisations may attain sustainable expansion and competitive advantage in the changing South African market. Workplace engagement and motivation among employees are essential factors influencing organisational performance in South Africa.

Recent trends show that South African employees demonstrate higher engagement levels than their global counterparts, with an engagement rate of 29%, exceeding the global average. Factors contributing to this positive trend include strong labour rights, effective management practices, and comprehensive employee engagement programmes. These programmes typically include performance evaluations, mentorship opportunities, and work-life balance initiatives, which together improve job satisfaction and motivation.

The relationship between employment and motivation is complex, encompassing factors such as job security, opportunities for career development, and recognition programmes. Research indicates that organisations employing effective performance management practices generally exhibit increased employee engagement levels. The implementation of employment equity policies positively influences employee motivation by fostering fairness and inclusion.

8. Recommendations

To maintain elevated employee engagement and motivation, South African organisations ought to:

- *Improve performance management systems:* Establish regular performance evaluations and ongoing feedback processes to ensure alignment with organisational objectives and employee expectations.
- *Invest in career development:* Invest in career development by offering training and development opportunities that facilitate professional growth and enhance employee motivation.
- *Encourage a constructive workplace:* Cultivate a collaboration, support, and inclusivity culture to enhance employee value and engagement.
- *Recognise and reward achievements:* To enhance morale and motivation, acknowledge and incentivise employee achievements through awards, bonuses, and verbal recognition.
- *Promote work-life balance:* Establish policies that facilitate flexible working hours, remote work opportunities, and sufficient time off to improve job satisfaction and motivation.

Understanding and leveraging the relationship between employment and motivation enables South African organisations to attain sustainable growth and competitive advantage in a dynamic market.

Conflict of interest

The author declares no conflict of interest.

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Media Synchronicity Effects on Telecommuters' Working Experience

Gabriel Almeida Kilson and Patrícia Tavares

Abstract

The widespread adoption of work from home has ignited a critical debate surrounding the necessity of in-office attendance and its influence on organizational performance. A central concern is that reduced face-to-face interaction might impede internal communication and overall effectiveness. Drawing on Media Synchronicity Theory, this chapter explores how employees experience media synchronicity in relation to shared understanding, contribution visibility, and performance evaluation. To investigate these experiences, we adopted a phenomenological approach, conducting online interviews with full-time telecommuters across various professional settings. Our findings challenge the conventional view, demonstrating that telecommuting does not inherently hinder complex discussions. Instead, telecommuters strategically select media options based on the communication context, enabling them to achieve high-quality communication. We further highlight the limitations of relying solely on quantitative metrics for assessing performance in highly interactive, non-repetitive roles, advocating for regular, synchronous communication between employees and managers. This chapter concludes with practical, managerial implications for optimizing internal communication and informing telecommuting policies.

Keywords: telecommuting, media synchronicity theory, internal communication, shared understanding, performance evaluation

1. Introduction

The post-COVID-19 world presents a fascinating dichotomy: a strong employee preference for flexible work arrangements [1] directly clashes with a growing executive desire for a return to traditional office settings at major companies like Amazon, Disney, JPMorgan, and Zoom [2]. This fundamental misalignment is not merely a matter of preference; it creates considerable uncertainty for organizations struggling to maintain productivity and foster a cohesive workforce. It compels us to ask: Is in-office attendance truly indispensable for achieving positive organizational performance? We argue that addressing this pivotal question requires a nuanced

exploration of employees' internal communication experiences in telecommuting environments—a critical area still largely overlooked in academic discourse.

Despite the widespread use of Information and Communication Technologies (ICTs) in daily work, ongoing concerns persist that the lack of synchronous face-to-face interaction can lead to increased misinterpretations [3]. Moreover, telecommuting often triggers a change in communication behaviors, resulting in greater reliance on text-based exchanges at the expense of richer voice and video interactions. This change can significantly hinder communication effectiveness and, importantly, stifle the development of innovative ideas [4]. Given the strong desire for remote work among professionals, companies face pressing challenges in maintaining essential functions and fostering effective collaboration. Therefore, there is a clear and urgent need to thoroughly examine how telecommuting impacts internal communication, particularly regarding its most critical aspects for the employee experience.

Drawing on Media Synchronicity Theory [5], this chapter explores employees' views on how telecommuting affects three key elements of organizational success:

- The development of a shared understanding of their role within the company.
- The visualization of their contributions to the company.
- The effectiveness of performance evaluation processes regarding their contributions.

Understanding how telecommuting influences these areas is essential for organizations seeking to effectively and sustainably navigate the evolving work landscape, as well as to greatly improve our understanding of the impact of alternative work arrangements on organizational performance.

To achieve this, this chapter begins by defining telecommuting and distinguishing it from similar concepts. It also explores the influence of various media options on communication experiences through the lens of Media Synchronicity Theory. We then transition to a detailed discussion of the implications of telecommuting for developing shared understanding, visualizing contributions, and evaluating performance. The Methods section provides a comprehensive overview of our research approach, including the participant selection criteria and the interview methodology. Subsequently, the Results section presents the four core themes identified during our data analysis, offering rich, qualitative insights into participants' perspectives. The Discussion section synthesizes our findings, outlining both their practical implications for managers and their theoretical significance, while addressing study limitations and suggesting avenues for future research. Finally, the conclusion succinctly reiterates the chapter's primary aim and central discoveries.

2. Main concepts

2.1 Describing telecommuting, teleworking, and remote work

Teleworking and remote work are often used interchangeably with telecommuting [6, 7]; however, these terms have distinct meanings. The recent introduction of “hybrid work,” which frequently lacks a clear definition, adds to the confusion.

Telecommuting entails the partial or complete elimination of commuting and can be categorized by frequency (full-time or part-time) and location (home-based or non-home-based) [8–11]. In essence, telecommuting involves an employee performing tasks from home (home-based telecommuting) or a location near their residence, such as a coworking space (non-home-based telecommuting), rather than commuting to their regular workplace (e.g., a shoe factory). Working from an alternative location daily generally qualifies employees as full-time telecommuters, although this classification can be flexible depending on the interpretation of “every day.” This chapter adopts Kilson and Tavares’s definition of full-time home-based telecommuters as “professionals who are allowed to perform their work from home on a daily basis,” who may “work from home 100% of the time, only having non-regular/ sporadic in-person meetings in cases where the company has physical space” (p. 5) [12]. Conversely, part-time employees are those with a regular, recurring obligation to work at the company premises. Although this definition is specific to home-based telecommuting, it can include full-time non-home-based telecommuters by substituting “home” with a location like “coworking space.”

This categorization is important because different types of telecommuting lead to varied work experiences. For instance, working from a coworking space may involve interaction with professionals from various companies, unlike working from home. Similarly, part-time telecommuters usually have more in-person interaction with colleagues than full-time telecommuters.

Teleworking, closely related to telecommuting, is defined as “the substitution of telecommunications technology for work-related travel” (p. 413) [11]. Unlike telecommuting, which focuses on reducing or eliminating commutes, teleworking can occur virtually anywhere, including at home, the office, or a park. For instance, when an employee at the shoe factory works from the company’s premises and uses her cell phone to communicate with a colleague at another plant, she is teleworking. Teleworking is a widespread practice facilitated by ICT, and it does not require advanced technology; even tools like the telegraph illustrate its historical prevalence (e.g., smoke signals or carrier pigeons). Remote work is any job performed physically away from the employer or manager [9]. For example, when the shoe factory employee visits a shoe store to present products and uses her tablet to record customer feedback for the marketing team, she works remotely. In this scenario, she is also teleworking. Conversely, telecommuting includes both teleworking and remote work [9].

The concept of hybrid work gained significant traction as COVID-19 restrictions eased and traditional commuting patterns re-emerged. While it typically denotes part-time telecommuting, the term is often used without explicit clarification, leading to varied interpretations. For instance, a schedule where an employee works from the office in the morning and from home in the afternoon could be labeled hybrid work. However, this example differs from telecommuting because it does not involve reducing or eliminating commuting. Therefore, hybrid work can represent a distinct work arrangement.

2.2 Communication synchronicity

Communication encompasses three core elements: a transmitter (sender), a channel (transmission means), and a receiver. The interaction of these elements creates the medium. Group communication entails two key processes: information conveyance and convergence on meaning [13]. Conveyance is the transmission of raw

information, followed by individual interpretation. The receivers process this shared information to grasp its meaning. Subsequently, convergence involves sharing these interpretations to reach a common understanding [5, 13, 14].

Consider the shoe factory employee: her online forms detailing visits to shoe stores convey information to the marketing team. Their follow-up meeting to clarify notes and discuss store interest seeks to reach a consensus on the best sales approach.

Numerous media options exist for communication, each possessing varying media capabilities – “potential structures provided by a medium which influence the manner in which individuals can transmit and process information” (p. 583) [5]. The degree of each capability affects communication performance by shaping conveyance and convergence [5, 13, 14]. The relative degree of these capabilities determines a medium’s synchronicity, directly impacting both conveyance and convergence [5, 13, 14]. For instance, phone calls facilitate synchronous communication more effectively than written documents.

Media Synchronicity Theory (MST) details how media capabilities influence a team’s communication performance, affecting both information conveyance and meaning convergence [5]. **Table 1** outlines these five capabilities and their implications. **Table 2** provides examples of media and their relative capability degrees.

Asynchronous media generally excel at conveying information, while synchronous media are better suited for converging on meaning. Conveying complex or new information often requires time for assimilation, making asynchronous options more favorable. Conversely, convergence, which aims for shared understanding, benefits

Capability	Relevance to communication
<i>Parallelism.</i> Capability to concomitantly transmit messages from different senders [5].	Higher parallelism enables more simultaneous participation, increasing potential ideas but potentially reducing individual focus [14]. Parallelism becomes more important for information conveyance with larger groups [13].
<i>Rehearsability.</i> Capability to revise a message before sending it [5].	Rehearsability can hinder communication because the time taken to compose messages reduces synchronicity [5] and may lead to increased user fatigue [15]. Furthermore, higher language proficiency among participants reduces the need for rehearsability [16].
<i>Reprocessability.</i> Capability to reaccess a message during or after the communication [5].	Higher reprocessability facilitates access to information for review and analysis, both during and after communication [16]. This is especially beneficial for complex, new, or extensive content [5, 13]. However, it can also induce anxiety, as participants may feel vulnerable knowing that past messages can be revisited [15].
<i>Symbol sets.</i> The number of ways information may be encoded [5].	A medium’s capacity to encode information with various symbols affects communication synchronicity. For example, gestures can convey reactions more quickly than typing [5]. More diverse symbol sets in written media, like emojis and images, can enhance social intimacy [15]. Nevertheless, having a wider array of symbols is not always better [13, 16]. While face-to-face communication permits a broader range of symbols than email, email might be more suitable for transmitting long sequences of numbers [16].
<i>Transmission velocity.</i> The time for a message to be delivered to its recipient [5].	Higher transmission velocity in media generally enhances synchronicity, allowing for faster feedback and improved coordination [5]. However, scheduling communication may also be necessary [13]. While rapid feedback through high-velocity media, such as instant messaging, can reduce communication fatigue, the opposite might also occur [15].

Table 1.
Media capabilities.

Media	Parallelism	Rehearsability	Reprocessability	Symbol sets	Transmission velocity
Email	High	High	High	Low-Medium	Low-Medium
Face-to-Face	Low	Low	Low	Low-High	High
Instant Messaging	Medium	Medium	Medium	Low-Medium	Medium
Telephone	Low	Low	Low	Medium	High
Video Conference	Low	Low	Low	Low-High	Medium-High
Voice Mail	Low	Low-Medium	High	Medium	Low
Paper-Written Documents	High	High	High	Low-Medium	Low

Based on Refs. [13, 14, 16].

Table 2.
Media capabilities degrees.

from rapid interaction through synchronous media to discuss different viewpoints [5, 13, 14]. However, higher synchronicity is not always ideal for convergence, primarily when language barriers exist; asynchronous media allow for review and thoughtful responses [17]. As communication norms and familiarity with media, tasks, and colleagues evolve over time, the need for convergence—and consequently, synchronous media—tends to decrease [5, 13, 14].

Inadequate information conveyance can lead to incorrect conclusions, and failed convergence hinders progress due to a lack of shared understanding [5]. Understanding these characteristics and their contextual relevance is crucial for quality communication. The most suitable media often depends on the context and objectives of the communication. A conversation may utilize different media to meet evolving needs [5, 13, 14].

For instance, a meeting to decide on a shoe factory's sales approach might involve face-to-face discussion, slide presentations (synchronous) for immediate interaction, and visual summaries. Simultaneously or subsequently, meeting minutes are emailed to participants (asynchronously) to ensure everyone has a record of decisions. Thus, different media can be used concurrently or sequentially based on communication demands.

3. Telecommuting implications for companies' activities

By working physically away from the rest of the organizational members, home-based telecommuters significantly reduce their dependence on transportation, while heavily increasing their dependency on ICT to mediate their interactions [10]. Thus, like any other work arrangement, home-based telecommuting offers plenty of opportunities and challenges for companies that adopt it. For example, on the one hand, telecommuting is positively associated with job satisfaction, employee-perceived autonomy [18], productivity [19], and work quality [20]. On the other hand, replacing in-person interactions with ICT-mediated interactions may challenge employees to develop a shared understanding regarding their activities, visualize their contributions to the company, and have a fair performance evaluation.

3.1 Shared understanding

Working from home may lead employees to reduce their synchronous communication, while increasing their use of asynchronous media. Employees might also spend more time communicating with colleagues with whom they have strong ties, spending less time with those with weaker connections. The increased use of asynchronous media can make conveying and understanding complex information more challenging [4]. For example, researchers have shown that prolonged use of text-based media during the convergence process, when tackling complex and ambiguous topics, results in adverse performance outcomes for participants during and after the communication. Over time, these cumulative adverse effects could reduce employees' productivity [21]. Moreover, due to the added cognitive effort needed when discussing complex ideas through text-based media, employees often focus more on information that supports their viewpoints than on information that challenges them, potentially leading to biased conclusions [3]. In this context, employees will likely share less knowledge, impacting a company's innovation capacity [4, 22].

Then, teams partially or entirely composed of telecommuters may face additional challenges in coordinating their activities [23] and establishing a shared understanding [24]. This raises important implications, as achieving a shared understanding is vital for a company because "[a] shared understanding of the team's goals ensures that the team is moving together toward a common vision" (p. 23) [25].

3.2 Contribution visualization

Helping employees visualize how their daily tasks benefit others can positively influence their performance [26, 27]. Specifically, when employees can see how their work has improved the lives of others, they feel more motivated [26]. Furthermore, employees who believe that others appreciate their work demonstrate enhanced job performance [27].

However, because home-based telecommuters do not directly experience what happens beyond their workspace, it might be harder for them to notice this connection and the positive practical effects of their work. For example, employees may not be able to perceive the positive emotions expressed by customers whose lives have been enhanced by the services they provided, because of the limitations of the symbol sets in the media [5]. Likewise, employees residing in remote areas might fail to recognize how their work has contributed to the development of the local community.

Then, because of the challenges in achieving a shared understanding in a virtual context [24, 25], it may be more difficult for employees to grasp why their roles are significant. Likewise, employees may struggle to visualize their contributions due to their ICT-mediated interactions, which cannot convey the relevant aspects that face-to-face interactions can [25].

3.3 Performance evaluation

Although telecommuters may perceive that the procedures regarding their compensation and treatment by supervisors are fair [28], the physical and temporal distance can create barriers for managers in evaluating employees' performance [6]. At the same time, employees may also encounter barriers in showcasing their contributions to the company, particularly when it pertains to tacit knowledge, a form of knowledge that is difficult to articulate explicitly [29–31].

In this context, managers may largely base their judgments on outcomes of activities that are more easily measurable [28, 32]. Indeed, the greater the frequency of telecommuting, the stronger the employees' perception that their performance is being assessed through output controls [33]. Furthermore, depending on the media selected and its capabilities, including symbol sets and transmission speed, employees and managers may encounter additional conflicts when discussing aspects of employee performance, as some comments may be interpreted as more aggressive or probing by either party [3].

4. Methods

This chapter is based on data from a study exploring telecommuters' perceptions of their participation in the company's organizational purpose. It included examining a series of work-related experiences, including those discussed above. Using a combination of purposeful and snowball sampling [34], all participants were full-time home-based telecommuters, except for one. Participants were "professionals who are allowed to perform their work from home on a daily basis" (p. 5) [12]. These employees have no formal obligation to commute to a traditional workplace. However, they may still make non-regular visits to the traditional workplace for sporadic work-related meetings, casual gatherings, and voluntary visits [12]. After emailing five participants who met the basic criteria, they were asked to introduce the study to other potential participants.

To access their perspectives, employees were interviewed remotely *via* Zoom during sessions that averaged 1 hour and occurred between October and November 2022. Employees responded to several questions, some of which followed a pre-defined script. They were free to express themselves, so no interview followed a strict order.

Resorting to a thematic analysis, we studied the interview transcriptions and selected every relevant statement for the study. While identifying relevant statements, we needed to answer two questions: "a. Does it contain a moment of the experience that is a necessary and sufficient constituent for understanding it? b. Is it possible to abstract and label it?" (p. 120) [35]. After interviewing 23 participants, we ceased data collection due to data saturation.

The participants' ages ranged from 26 to 54 (Mean = 36.48, SD = 7.16), with females representing 69% of the sample. Overall, participants were highly skilled, with 78% holding at least a bachelor's degree. They worked in various fields, including customer support, information technology, geoprocessing, and project management. Employees worked for 14 different companies, most of which operated in multiple countries. The number of employees ranged from a few dozen to hundreds of thousands. Their sectors included lodging, cybersecurity, logistics, telecommunications, and more. Most are based within the European Union, with a few in North and South America.

5. Results

Four main themes emerged during the data analysis. For each theme, it was possible to identify subthemes. **Table 3** lists all the themes and their respective subthemes.

Themes	Subthemes
Experience of working from home	Reason for working from home
	Benefits of working from home
	A lonely job
	Distance communication advantages
	Self-perception of productivity
Social interactions at work	Frequent contact only with direct coworkers
	Media usage context
Organizational onboarding experience	Learning experience of work activities
	Connection of the work with the rest of the organization
Organizational contribution and performance evaluation experiences	Visualization of self-contribution and that of coworkers
	Performance evaluation

Table 3.
List of themes and subthemes.

5.1 Experience of working from home

5.1.1 Reason for working from home

Employees' reasons for working from home were twofold: circumstantial or intentional. Some found remote roles appealing during job searches or due to practical reasons like company location. The COVID-19 pandemic also mandated remote work, which some employees later preferred. Others actively sought remote positions for improved work-life balance, valuing flexibility, commute savings, and location independence.

"So, the company was Argentinian, I was in Colombia, and the position would be to manage the Colombian market for this Argentinian company. And, as this company did not have a physical office, the virtual model was adopted" (Participant 6).

"I think it is a matter of freedom and flexibility. My previous job was 9 hours a day plus commuting. [...] I was always eating outside, so a lot of food, or worse quality food than cooking at home" (Participant 9).

5.1.2 Benefits of working from home

Employees cited several benefits of working from home. The most common were time saved from commuting, and greater flexibility in managing work around personal needs, such as childcare. Increased social comfort was another key advantage, with employees feeling more at ease in their own space, and having more control over workplace interactions. Both male and female employees noted the shift to more comfortable attire, like pajamas. Female respondents also reported reduced social pressure regarding their appearance (e.g., makeup, high heels), and an increased sense of personal safety, such as not having to walk home alone at night.

"Daily, I have the freedom to choose my schedule and how I do things as long as the objectives are met. [...] I really like working toward goals and having the freedom to manage my time" (Participant 5).

"I have pets, so to be with them is a very important part of my life [...] So, whenever I had to go back to the office for my previous role, I thought I missed that the most at the time I had it with my pets" (Participant 19).

"Sometimes, we catch rude customers, and we have to try to take a deep breath and not respond in the same way [...] Sometimes, I think I am glad I am behind the phone. If I was there at the counter, I do not know how I would be able to manage the situation" (Participant 10).

5.1.3 A lonely job

The physical and temporal distance of remote work often leads to feelings of loneliness and isolation among employees. They reported a significant reduction in social interactions and found that ICT-mediated communication, such as video calls, cannot fully replace face-to-face contact. However, respondents noted that video communication can enhance understanding and build trust.

"[...] it is a bit of a lonely job. [...] working in an office, has contact with colleagues. There is another type of experience that is not alone. [...] It is not the same thing as being in a space with other people having lunch" (Participant 4).

"I realize that it is nicer to see other people's faces when a person is talking because if the person has the camera off, you do not know that the other person is even there. [...] I can tell if she is in a good mood, if she is not in such a good mood" (Participant 22).

5.1.4 Distance communication advantages

A key communication advantage noted is the ability to quickly and directly share information across an organization while preserving message integrity. Employees also believed that ICT streamlines the often complex coordination of communications involving multiple individuals, facilitating same-day or simultaneous interactions.

"I talk to 100 people a day [...] I do not think it was even possible to have so many people in the office. Also, it would be harder to be side-by-side with a colleague from a certain department who has a question. [...] I think it also ameliorates a lot in terms of communication as it avoids many conflicts [...] if the person responds more harshly, I am somewhere else doing something else" (Participant 8).

5.1.5 Self-perception of productivity

Many employees felt more productive because they saved time by not commuting to work, had greater freedom to control their working schedule, had reduced social interactions, and had constant access to work. Furthermore, being at home does not alter their level of professionalism. They remain highly aware of the importance of keeping everything organized and completing all their tasks as if they were directly supervised.

"[...] I am going to call someone in the office because I need to speak to someone. That is it. It is over. [...] Now I have seven more hours of peace. So the fact that we can manage the amount of social contact, I think it is good [...]" (Participant 18).

"[...] since there is no direct boss, I am responsible for my area. [...] The more up-to-date and organized things are, the faster I can respond to requests. Therefore, what I do outside the measurable parameters, which is not much more than what I do, I would do anyway" (4).

5.2 Social interactions at work

5.2.1 Frequent contact only with direct coworkers

Employees mainly interact with their immediate coworkers regularly. Wider company communication is usually restricted to events, scheduled meetings, and major announcements.

"Sometimes, of course, I interact with other teams [...], but on a day-to-day basis, my interaction is with my team. But there are days when I do not even talk to anyone. I have my work to do and focus on it" (Participant 9).

5.2.2 Media usage context

While respondents favored audio, and sometimes video, for complex topics and varied perspectives due to enhanced contextual cues, like facial expressions, that aid in synchronous communication and understanding, they also identified drawbacks. Frequent, especially unannounced, audio calls were perceived as intrusive, causing interruptions and demanding undivided attention, thereby impeding multitasking. Consequently, unscheduled audio calls are generally reserved for urgent situations. Textual communication emerged as the most prevalent choice, with some respondents emphasizing its critical role in record-keeping for legal reasons, progress tracking, and creating shareable documentation.

"[...] when there are meetings that are not to ascribe tasks but to discuss the direction of the work, which is a little more brainstorming, I prefer calling. It is easier to call because there will be several people involved, there will be ideas coming from different sides [...]" (Participant 23).

"[...] because we also work with people from different time zones, and sometimes there is a need to communicate with these people. As they are not available at the moment, it makes sense to communicate by text and wait for the person's response" (Participant 13).

5.3 Organizational onboarding experience

5.3.1 Learning experience of work activities

Employees reported that learning their tasks and procedures remotely was not impeded by physical distance. The online resources and the nature of their

computer-based work allowed for a learning experience similar to in-person onboarding. Interestingly, many employees noted the benefits of remote onboarding, such as increased access to international colleagues, and the impression that virtual processes were often better organized than traditional ones. However, they also encountered learning difficulties, primarily attributed to a lack of clear procedures and insufficient support from employers, rather than to the challenges of remote work itself. The only difficulty directly related to telecommuting was the less frequent communication, which had the potential to hinder their learning.

"We had our Google Drive, and there was a shared folder with information about the company [...] about what was expected and the step-by-step of what we should do [...] We could access these documents at any time" (Participant 11).

"If I was working remotely from the beginning, I think that maybe I would still be missing things, precisely because of this issue of communication that, whether we like it or not, ends up being reduced when we are telecommuting" (Participant 14).

5.3.2 Connection of the work with the rest of the organization

Most employees explicitly stated an understanding of how their contributions connect to the broader company, with some providing concrete examples of this interconnectedness and illustrating how internal process failures can create cascading effects throughout the organization.

"[...] I can develop my work, but then there comes a time when I am dependent on the work of the technology department. And if the technology department has limitations in terms of human resources, my work is negatively impacted" (Participant 6).

5.4 Organizational contribution and performance evaluation experiences

5.4.1 Visualization of self-contribution and that of coworkers

Employees primarily visualize their and their coworkers' contributions through the tangible final outputs of their tasks. This quantitative perspective was viewed positively by some, while others felt it overlooked important, less quantifiable aspects of their work. Notably, respondents indicated that working remotely did not affect their perception of their contributions, as their online tasks and observable results remained consistent.

"People evaluate my work by my results and not by my posture during the eight hours of work. [...] that is why I think remote work is good because if the results are presented, people cannot question being online or the number of messages people put in public channels [...]" (Participant 18).

"So, my area is remote sensing, so it is already remote. [...] in that sense, whether it is face-to-face or not [...] it is the exact same experience" (Participant 14).

Opinions varied regarding the influence of feedback media on its perception. Some employees believed the medium was inconsequential, with word choice being paramount. However, others felt the media did matter, with some valuing channels

that conveyed more contextual signals, such as voice tone and facial expressions, which they believed could facilitate better understanding.

"Yes, there are things I prefer to be on a call. Precisely because of the more social part of the issue, to discuss more difficult things or more positive things, I think it is good to have this moment" (Participant 12).

When asked about the impact of their work, employees generally reported a clear awareness of its practical effects. Observing positive outcomes was considered a significant motivator and a positive reinforcement of their professional identity.

"I feel good for being able to help people and for feeling that I have a beneficial impact on society" (13).

5.4.2 Performance evaluation

Employees frequently reported that performance evaluations take place during their regular interactions with supervisors. The lack of a formal, structured evaluation process and direct progress monitoring was largely attributed to a high level of trust between employees and their supervisors. This informal approach to evaluation showed varying levels of satisfaction based on the nature of the work. Employees whose tasks were easily registered and quantifiable tended to express greater satisfaction with their performance evaluations compared to those with less measurable responsibilities. Consequently, effective communication between employees and supervisors was identified as a crucial element in assisting employees with less tangible tasks and demonstrating their progress. Ultimately, most employees viewed their performance evaluations as fair, primarily due to these direct and ongoing interactions with their supervisors.

"So, surprisingly, it works if you really trust people and show them that they have a certain responsibility [...] you feel that you are working for your name because, on each email, it is your name" (Participant 15).

"[...] being at home, if I have results, it means I worked, but if I do not have results, it does not mean I have not worked" (Participant 1).

"In departments where I felt that communication was better, my work was more recognized than in others [...] the fact that it is remote is not the biggest problem [...]" (Participant 18).

6. Discussion

Employees confirmed that working from home often reduces workplace distractions [8, 36], particularly concerning interruptions from colleagues, such as unscheduled conversations. Indeed, the greater control over their social interactions enables them to choose whom they communicate with, and for how long. As a result, employees reported that their interactions were primarily confined to direct coworkers, which aligns with recent research showing that working from home reduces communication frequency and network dynamism [4, 37].

Interactions *via* media characterized by high transmission velocity and low reprocessability, such as telephone calls, typically demand employees' undivided attention, necessitating the interruption of ongoing tasks [38]. Therefore, corroborating previous research [15, 16], some employees perceive telephone calls as intrusive and best reserved for urgent communication. This, coupled with the negative association between team inclusion and asynchronous media like email [17], may contribute to a decreased willingness to communicate among remote workers, potentially explaining the observed reduction in social interactions and increased feelings of isolation.

In line with this, employees reported an increased focus [37], enhancing their self-perception of productivity. These perceptions align with prior research linking telecommuting to improved productivity [19]. This rise in perceived productivity may also be attributed to employees' greater control over their work routines, enabling them to optimize the order and timing of their tasks. Furthermore, the flexibility in managing breaks supports the positive relationship between telecommuting and employee-perceived autonomy [18].

6.1 Shared understanding

Working from home leads employees to communicate more frequently through instant messaging [4]. This behavior can be attributed to the medium/high rehearsability and reprocessability of text-based media. Text-based communication allows recipients to access messages conveniently without interrupting ongoing tasks. Furthermore, it offers an opportunity for reflection before responding. The enduring nature of text-based communication also establishes it as a valuable repository of information, enabling employees to revisit details of past discussions or task procedures. It also records agreements, which is particularly important for legal compliance when interacting with external stakeholders. Moreover, as employees became more familiar with their tasks and their coworkers' communication patterns, their reliance on synchronous media like telephone or video conferences decreased. This shift occurred as shared understanding developed, reducing the need for conveying supplementary nonverbal cues [5].

While previous studies have highlighted the potential threat of increased text-based communication to discussions of complex and unstructured topics [3, 4, 21, 22], our findings suggest a more nuanced perspective. Employees in our study demonstrated an awareness of different media capabilities and could discern the most appropriate media for specific communication needs. Notably, most employees reported using audio or video calls for brainstorming sessions and discussions involving complex or unstructured conversations. As a result, employees generally rated their communication effectiveness positively, sometimes even surpassing their experiences in co-located settings. This improvement is attributed to the broader array of communication media available following the transition to remote work. They reported effective comprehension and a sense of being understood. Given the routine nature of most organizational tasks, full-time remote workers are likely to continue their increased reliance on text-based media while decreasing their use of other channels. As long as employees maintain the autonomy to choose the most suitable media, this increased adoption of text-based communication does not seem to pose a significant threat to achieving shared understanding.

In the end, the primary impediments to achieving a shared understanding of roles among employees pertained to the quality of internal communication. Specifically, three key issues emerged: lack of clarity, inconsistent frequency, and information

segregation. Regarding clarity, employees reported instances of information conveyed through jargon, or lacking sufficient contextualization, hindering comprehension, particularly for those not directly involved. Furthermore, the frequency of updates regarding company activities and objectives decreased over time, leaving many employees uninformed. Finally, information segregation was identified as a problem, with certain information selectively disseminated, based on communicators' assumptions of irrelevance to others. Importantly, none of these issues are inherently linked to telecommuting or ICT-mediated communication. Rather, they relate to the fundamental management of internal communications and can manifest in various organizational contexts, including traditional co-located workplaces.

6.2 Contribution visualization

Beyond its importance for task completion, effective internal communication significantly influences telecommuters' professional self-perception and, consequently, their well-being [37]. Our findings underscore the critical role of clarity regarding how employees' roles contribute to organizational value, reinforcing a sense of relevance. This aligns with prior research indicating that employees experience greater motivation when they perceive the positive practical outcomes of their work [26, 27]. In addition to visualizing their contributions, employees frequently reported understanding how their colleagues' work interconnected with the broader company and recognizing the practical effects of their contributions. Similarly, many of their colleagues could also acknowledge their contributions. Consequently, employees indicated that physical distance did not pose a limitation in this regard. Indeed, for some whose work is entirely computer-based and location-independent, home-based telecommuting did not alter their perception of the practical effects of their activities, highlighting that the physical workspace can be irrelevant for contribution visualization depending on the nature of the job.

However, the intangible aspects of work that were not easily quantifiable or communicable through software were often overlooked. Consistent with this, there were reports indicating that managers did not share information about specific employees' ongoing projects with others, fostering information segregation. For example, colleagues often lacked visibility into the contributions of employees whose work had a long-term outlook and whose impact was not immediately observable. Similarly, colleagues were frequently unaware when these employees addressed urgent and unpredictable issues that could delay their results. These circumstances led to frustration among the affected employees due to concerns about potential negative perceptions of their performance by their colleagues.

6.3 Performance evaluation

Managers, like employees, often evaluate contributions based on final outputs. As a result, contributions that are not easily captured by software may be overlooked unless explicitly discussed during meetings. Consistent with prior research [38, 39], employees emphasized the importance of establishing synchronous communication to foster mutual understanding of diverse perspectives. In this context, media characterized by high transmission velocity and rich symbol sets, such as audio and video calls, are the most suitable options. Additionally, both the chosen communication medium and the language used during performance discussions are critical in preventing misunderstandings regarding both content and tone [3]. However, as noted in

Ref. [40], it is essential to balance the level of synchronous interaction with managers to avoid creating a perception among employees of constant monitoring.

Despite the importance of regular feedback from direct managers in remote work settings [37], some employees reported a decline in performance feedback after shifting to home-based telecommuting. In this context, feedback was often provided only during scheduled performance discussions or when explicitly requested, highlighting the need for proactive initiatives, such as socialization events, to foster the sharing of feedback among organizational members [37].

Ultimately, our results corroborated the challenges associated with remote performance evaluations faced by both employees and managers [28, 32]. Employees reported difficulty demonstrating their work progress due to the inherent inability to quantify certain aspects of their roles. While tracking quantifiable metrics like mouse clicks or hours worked may be effective for repetitive tasks with limited interpersonal communication [41, 42], it falls short for roles with an intangible nature, where the relationship between time and output is less direct [41]. Still, employees demonstrated an ability to discern and select media capabilities most relevant to specific situations. Thus, remote management challenges can be mitigated by strategically aligning communication media with the context [40].

6.4 Theoretical implications

Beyond supporting [4] observations regarding shifts in employee communication behaviors after home-based telecommuting adoption, our findings offer insights into the underlying reasons. These include both readily apparent factors, such as the absence of casual, unscheduled interactions, and less obvious factors, like employees' heightened focus on individual tasks. This increased focus also helps explain the tendency for telecommuters to intensify communication with direct collaborators, while reducing interactions with more peripheral organizational members who do not directly impact their immediate tasks.

Prior research has raised concerns about the potential limitations of ICT-mediated interactions, particularly text-based communication, in conveying and comprehending complex topics [3, 4, 21, 22], suggesting long-term negative impacts on employee performance and organizational innovation. However, our results indicate that employees carefully consider the context when selecting their communication methods, opting for richer alternatives like voice or video calls, incorporating visual aids (e.g., pictures, drawings, and screen sharing), or combining media when the topic is unstructured or requires extensive discussion.

Similarly, while home-based telecommuting has been associated with difficulties in accurately evaluating employee performance and contributions [6], our findings indicate that, by leveraging various media options, employees and managers can offset the absence of passive communication through enhanced active communication. Employees and managers can use voice or video calls to clarify perspectives and resolve misunderstandings. Thus, our results do not indicate an inherent flaw in telecommuting that hinders effective organizational functioning. Instead, training organizational members on the capabilities of different media [39] and adapting internal communication processes to the remote context can address many commonly cited challenges.

Last, our research supports [41]'s claim that relying solely on easily quantifiable work inputs to monitor productivity in non-repetitive and intangible roles is inadequate, as these metrics do not capture essential aspects of the job. Therefore,

our findings emphasize the vital importance of establishing regular, high-quality synchronous communication between managers and employees for enhanced performance evaluation. These interactions are also crucial for ensuring that employees comprehend their role within the company and how their contributions align with strategic objectives.

6.5 Practical implications

6.5.1 Internal communication quality

The primary challenges for home-based telecommuters stem from internal communication quality, not distance. Key issues affecting effectiveness are a lack of clarity, inconsistent frequency, and information segregation. In modern organizations, most stakeholder interactions rely on ICTs, which increase with organizational growth and make direct observation impractical. Effective ICT-mediated communication is crucial for better internal communication.

- *Lack of clarity:* Internal information often lacks context or uses jargon, hindering understanding, especially across different departments and for new hires who need background. Crucial company-wide information should use accessible language for maximum comprehension and engagement.
- *Frequency inconsistency:* While initial information flow is high, organizational communication often decreases. This inconsistency also affects performance evaluation discussions. The absence of passive communication in remote settings requires more active communication. Therefore, managers and employees should establish regular two-way interactions for updates, expectations, insights, and experiences [43]. This could involve implementing structured, regular check-ins or utilizing communication platforms that facilitate two-way dialog and feedback.
- *Information segregation:* Characterized by incomplete or selective information sharing, information segregation can fragment an organization, leading to conflicting objectives, internal conflict, and dissatisfaction. To ensure alignment and transparency, all employees should have access to comprehensive information about the company's present and future, and managers should empower employees to determine their own access to information. This proactive approach to information sharing fosters a sense among employees that they are truly participating in internal communications and belong to the rest of the company, consequently increasing their willingness to contribute by openly sharing their thoughts [44].

In conclusion, these challenges are not inherent to telecommuting or ICTs but reflect basic internal communication management issues applicable to all work environments. Clear, consistent, and inclusive communication strategies are vital for an informed and engaged workforce, regardless of location.

6.5.2 Full-time home-based telecommuting adoption

When considering the adoption of full-time home-based telecommuting, managers must evaluate several critical factors. Firstly, local job dependability is paramount.

Roles that require physical presence at a specific location due to the need to access specialized resources (e.g., heavy machinery) or provide location-specific services (e.g., hotel reception) may present significant challenges or preclude telecommuting implementation.

Secondly, organizational readiness is crucial. Managers should assess the company's preparedness by addressing key questions: Can employees access all necessary information remotely to perform their tasks effectively? Are all organizational members proficient in using various media to ensure clear and unambiguous communication? Do managers possess the skills and tools to evaluate employee performance remotely and fairly? Can employees effectively demonstrate their contributions to the company remotely?

Finally, the potential impact on the company's stakeholders must be considered carefully. For instance, is in-person interaction between employees and customers essential to the desired customer experience? A thorough evaluation of these aspects enables managers to make informed decisions about the feasibility and strategic implications of adopting full-time home-based telecommuting.

6.6 Limitations and future research

A limitation of this study lies in the self-reported nature of the data, as employees sometimes found it challenging to articulate specific aspects of their communication behaviors, potentially due to a lack of prior, in-depth reflection. Future research should employ alternative data collection methods that encourage more thoughtful and detailed responses. Qualitative surveys with open-ended questions, story completion techniques, or vignettes could provide richer insights by allowing participants more time and flexibility to elaborate on their experiences and add nuanced perspectives.

Furthermore, while our sample exhibited diversity across several dimensions, it was not exhaustive. Most participants were female, highly educated, relatively young, working from home without roommates during work hours, and engaged in roles that were easily adaptable to computer-based execution. Future research examining a more demographically and professionally diverse sample is essential to provide a broader understanding of remote communication experiences across various employee profiles and job types.

7. Conclusion

The growing tension between employees wanting to work from home and executives insisting on their presence in the office raised the crucial question of whether returning to the office is truly necessary for achieving positive organizational performance. This question's premise focused on whether completely replacing face-to-face interaction among employees would jeopardize the quality of internal communication. This chapter examined this question by exploring the internal communication experiences of full-time, home-based telecommuters, particularly how employees perceive media synchronicity regarding shared understanding, contribution visibility, and performance evaluation.

Examining employees' perceptions of developing a shared understanding of their roles within the company, we found that most employees find the processes for learning their tasks to be clear and that physical and temporal distance does not hinder this

learning. Furthermore, when considering the connection between their activities and the broader organization, along with the potential impact of their actions on company performance, employees show an awareness of their roles in both daily operations and long-term strategy objectives.

Similarly, investigating how employees perceive their contributions to the company, we found that the primary methods for visualizing both individual and collective contributions are through the tangible outputs of work activities. However, for employees whose work is less easily recognized or quantifiable, this output-centric perspective can lead to frustration in demonstrating their contributions. Importantly, the digital nature of many roles reduces the impact of physical and temporal separation on employees' perceptions of their contributions. Our findings also highlight the motivational significance of enabling employees to visualize the positive effects of their work.

Finally, exploring employees' perceptions of performance evaluation processes regarding their contributions revealed that performance feedback typically occurs during informal interactions with supervisors, facilitating a mutual exchange of perspectives. Aligning with the nature of their tasks, employees involved in easily measurable activities tend to express greater satisfaction with evaluation processes than those in more abstract roles. Furthermore, the media and language used to convey feedback are critical factors that influence employees' perceptions of these evaluations. Ultimately, employees indicate that clear, consistent, and open communication with their supervisors mitigates any perceived barriers to fair performance evaluation arising from physical and temporal distance.

In sum, our findings indicate that telecommuting does not inherently impede employees from establishing good-quality internal communication, and consequently, does not necessarily disturb employees' experience of these three aspects. The main factors hampering good-quality internal communication relate to how internal communication is managed, not to what media employees use. This is a matter that all companies, regardless of the work arrangements adopted, must consider.

Conflict of interest

The authors declare no conflict of interest.

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Automation and Adaptability: Regional Perspectives from Mexico's Northern Region on the Future of Work

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Abstract

This study explores the intersection between automation, labor adaptability, and the future of work in Mexico, with a specific focus on the northern state of Chihuahua located in the border with the U.S., drawing from global literature and empirical data obtained from a survey applied in 2024 to 152 automation-driven enterprises across the state. The research analyzes the structural characteristics of the aforementioned organizations, their economic behavior, and the challenges they face in a rapidly transforming labor market. By combining theoretical insights with the empirical data obtained, it is highlighted how automation can contribute to sustainability while also exposing social inequalities. These findings stress the importance of labor reskilling, business clustering, certification strategies, and policy frameworks to ensure an inclusive future of work in the region.

Keywords: labor trends, sustainability, reskilling, emerging economies, Latin America region

1. Introduction

The rapid advancement of digital technologies and automation is fundamentally transforming economies and labor markets worldwide, ushering in what some scholars term as “Secord Machine Age” [1]. Automation, as a pillar of Industry 4.0 is reshaping production systems, labor markets, and sustainability strategies worldwide. While developed economies have led this technological transition, less developed regions, including northern Mexico, are now engaging deeply with automation processes. In the state of Chihuahua, automation plays a critical role in manufacturing and industrial integration, particularly along the U.S.-Mexico border.

Manufacturing constitutes a fundamental pillar of Chihuahua's regional economy, with the IMMEX (Spanish acronym for Export Manufacturing Industry or

maquiladoras) sector alone employing over 413,000 workers across 480 establishments as of mid-2024, making it the fifth-largest contributor in Mexico [2].

The export-oriented manufacturing sector in Ciudad Juarez, along the U.S., stands as a pivotal driver of both regional and state economies. As early as 2024, Ciudad Juarez accounted for approximately 291,286 IMMEX/associated workers, making it the top municipality nationally in maquiladora employment. In contrast, capital city of Chihuahua employed 85,580 IMMEX workers, ranking fifth in the nation [2], representing the highest concentration of export-oriented manufacturing in Mexico.

However, despite a decade-long growth trend averaging 2.5% annually, IMMEX employment exhibited a 4.1% decline in city of Chihuahua, signaling early signs of automation-drive reductions (**Figure 1**) [3, 4].

As automation technologies are increasingly adopted—particularly robotics, programmable logic controllers (PLCs), and smart systems—in sectors such as automotive and electronics, routine production roles are likely to diminish. This structural transformation demands proactive workforce reskilling, redefinition of middle-skill jobs, and strategic upskilling to ensure employment resilience amid the ongoing transition to Industry 4.0.

This paper aims to connect international debates on automation and the future of work with regional empirical insights. Data obtained from 152 automation-driven enterprises in 2024 as a diagnostic assessment of the sector in Chihuahua, Mexico, is presented, adding to the body of literature discussing the social, environmental, and technological effects of automation.

Despite extensive global research, there is a significant lack of empirical focused on how automation affects workforce dynamics, skill requirements, and labor market adjustments in northern Mexico's export oriented manufacturing sector. Existing literature often focuses on developed economies or provides only macro-level analyses, leaving a critical gap regarding the nuanced, region-specific challenges and opportunities faced by Chihuahua's industrial workforce during the Industry 4.0 transition.

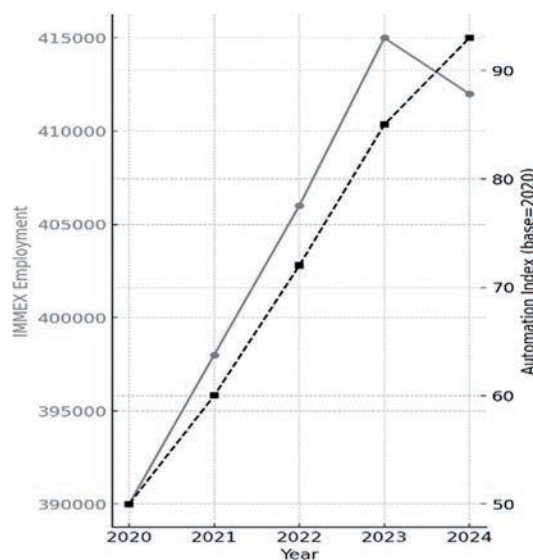


Figure 1.
IMMEX employment and automation index in Chihuahua, 2020–2024 [2–4].

This paper emphasizes the need for regional insights to inform policy and practice. Ultimately, the study aims to enrich the discourse by providing nuanced, context-sensitive analysis relevant to Chihuahua's manufacturing sector.

2. Relevant theoretical frameworks

There is no single, widely accepted theoretical framework that assesses automation, workforce adaptability, and sustainability all at once and thoroughly. However, a strong basis for multidimensional analysis could be achieved by the integration of two or more of the aforementioned dimensions, extracted from diverse and significant frameworks and contemporary studies. The main ones are described below:

2.1 Task-based model of automation and labor adaptability

The task-based framework developed by Acemoglu and Restrepo [5] provides a foundational and widely cited approach to understanding the complex interplay between automation and labor markets. Their model conceptualizes production as a composition of distinct tasks, some of which can be automated by capital (machines, algorithms), while others require human labor. Automation displaces workers by replacing labor in tasks where machines have a comparative advantage (the displacement effect), but it also generates new tasks that reinstate labor demand, often requiring higher or different skills (the reinstatement effect). This dynamic explains why automation can simultaneously reduce employment in certain tasks while creating new job opportunities in others, emphasizing the importance of labor adaptability.

Acemoglu and Restrepo's framework further advances the analysis by incorporating the balance between these displacement and reinstatement effects, highlighting that significant changes in labor share and employment patterns depend on whether new labor-intensive tasks emerge quickly enough to offset automation-driven job losses. They also emphasize that adjustment to these changes is neither seamless nor costless, as workers must acquire new skills and transition to new tasks, often with significant time lags and potential inequality implications, since skilled workers tend to benefit more from new task creation.

Complementing this, Autor [6] introduced the concept of routine-biased technological change, which underpins the task-based approach by demonstrating how automation disproportionately affects routine tasks—typically low and middle-skill jobs, while increasing demand for nonroutine cognitive and technical skills. Their empirical work provides a robust basis for understanding labor market polarization resulting from technological progress.

Brynjolfsson and McAfee [1] contribute a broader perspective on the implications of rapid technological advancement, warning that exponential progress in automation and artificial intelligence may outpace the labor market's capacity to adapt, potentially exacerbating inequality if effective inclusion and retraining policies are not implemented. Their analysis underscores the urgency of addressing skill mismatches and labor adaptability challenge in the digital age.

Together, these contributions form a comprehensive theoretical and empirical foundation for analyzing how automation reshapes labor demand, skill requirements, and inequality, highlighting the critical role of adaptability through retraining and policy interventions.

2.2 Integration of Industry 4.0 and sustainability

Recent research has highlighted the critical role of Industry 4.0 technologies in advancing sustainability across economic, environmental, and social dimensions. Conceptual models emphasize how smart manufacturing and digital transformation enhance resource efficiency, reduce environmental impact, and support social sustainability, with workforce upskilling identified as key enabler of these transitions [7]. These frameworks provide a comprehensive view of how digitalization can align industrial progress with sustainable development goals.

2.3 Sustainable automation and agile implementation

Complementing these insights, analytical frameworks have been developed to evaluate automation's dual impact on sustainable development, incorporating economic growth, social equity, and environmental considerations. Such models explicitly address labor market dynamics, including job displacement, reskilling need, and social inclusion, as integral to sustainability assessments [8].

Moreover, emerging research advocates for integrating agile methodologies and human-centered design principles into sustainable automation projects. These approaches prioritize adaptability through continuous learning and iterative feedback while emphasizing resource efficiency and social well-being, particularly in sectors like manufacturing and construction, thus fostering more resilient and socially responsible automation implementations [8, 9].

2.4 Circular economy, ethics, and governance in automation

Emerging research demonstrates that automation plays a critical role in advancing circular economy objectives by optimizing processes such as robotic assembly and disassembly, thereby enhancing resource efficiency and minimizing waste throughout product lifecycles [10]. This synergy between automation and circular manufacturing fosters not only environmental sustainability but also economic resilience by extending asset lifespans and reducing raw material consumption.

Simultaneously, scholars emphasize the necessity of robust ethical frameworks to preserve human agency within increasingly automated systems. Ensuring transparency, accountability, and human oversight is fundamental to maintaining social trust and preventing the erosion of individual autonomy in decision-making processes mediated by artificial intelligence and robotics [11].

From a governance standpoint, balancing technological innovation with social responsibility is paramount. Evaluations of AI-driven systems must extend beyond efficiency metrics to include assessments of social trade-offs, such as equity, labor market impacts, and potential inequalities [12].

Together, these global insights establish a critical foundation for analyzing automation's multifaceted impacts at the regional level, informing policies and strategies that reconcile technological progress with sustainability and social well-being.

3. Automation and the future of work: Global and regional perspectives

Automation's impact on employment has been rigorously analyzed by Frey and Osborne [13], who quantitatively estimate that nearly 50% of U.S. jobs are at high risk of

automation within the next few decades. Their study uses machine learning techniques to assess the susceptibility of occupations to computerization, highlighting the potential scale of labor market disruption and the urgent need for workforce adaptation.

Expanding on this, Frey's book "The Technology Trap" [14] provides a broader historical and economic perspective on technological change. It explores how automation interacts with labor markets, capital, and power relations over time, emphasizing that the social and economic consequences depend heavily on institutional and policy responses. Together, these works offer complementary insights: one quantifies immediate automation risks, while the other contextualizes these risks within long-term socioeconomic dynamics.

While automation holds significant potential to advance sustainability by enhancing energy efficiency and reducing waste, its benefits are not automatically equitably distributed. Without the guidance of inclusive and well-designed policies, the implementation of automation technologies may inadvertently exacerbate social and economic inequalities, as highlighted in prior research [5–8, 15].

The intersection between automation, labor adaptability, and the future of work in Chihuahua, Mexico—a northern border state with significant ties to the U.S.—reflects a complex dynamic driven by technological transformation, economic policy, and cross-border integration. The conceptual framework that follows analyzes this nexus by consolidating significant findings from recent studies (2021–2025).

3.1 Technological disruption and industrial transformation

Automation, artificial intelligence (AI), and Industry 4.0 are reshaping the region's manufacturing sector, historically reliant on labor-intensive maquiladoras. This shift is driven by:

- Global competitiveness: Rising wages and supply-chain reconfiguration post-COVID incentivize automation to maintain cost efficiency [16].
- Product quality demands: Automation technologies, including AI-based tools such as visual inspection systems, are increasingly used to improve production precision, reduce rework, and enhance reliability.
- Labor displacement: Automation reduces reliance on manual labor, with Ciudad Juárez's manufacturing sector already shifting toward high-skill roles [16].

3.2 Labor market polarization and skill gaps

Automation generates a divided labor market:

- Skill polarization: Automation in Chihuahua's manufacturing sector is driving a decline in low-skill roles such as assembly-line work while increasing demand for technical and cognitive skills, including robotics maintenance, AI management, data analysis, and problem solving. This transformation reflects broader regional trends, where rapid technological change intensifies skill mismatches and impacts labor market inclusion [16, 17].
- Training misalignment: Despite recognition of these critical future skills, only 5% of Mexican small and medium-sized enterprises (SMEs) currently leverage

real-time automation insights, highlighting a significant gap in workforce readiness. Higher Education Institutions in the state continue to face challenges aligning their curricula with evolving industry demands, which exacerbates skill mismatches [16, 17]. In this context, the Economic Commission for Latin America and the Caribbean (ECLAC) stresses that skill mismatches across the regions hinder labor market inclusion [18]. In this regard, the International Labour Organization (ILO) emphasizes that educational policies must prioritize the development of technical skills adapted to technological change, particularly in sustainability and digitalization, to ensure long-term labor market inclusion [19]. Meanwhile, government initiatives supporting engineering and technical graduates offer a promising foundation, though challenges in soft skills and adaptability remain.

- Policy-driven wage pressures: Elevated minimum wages in Mexico's border zones, including Chihuahua, accelerate automation adoption as firms offset labor costs [16]. The OECD estimates that nearly 19% of Mexican jobs face a high risk of automation, above OECD average, with northern states like Chihuahua particularly exposed due to their manufacturing focus [20, 21]. Globally, World Economic Forum (WEF) projects that automation will simultaneously create and displace jobs, with net growth favoring high-skill roles, underscoring the need for proactive policies to manage transitions and mitigate inequality [22]. However, more detailed OECD estimates, which analyze automation at the task level and not just at the occupation level, suggest that the risk can be nuanced according to the sectoral structure and labor adaptability [23].

3.3 Border-region dynamics

Northern region proximity to the U.S intensifies exposure to:

- Cross-border technology transfer: Rapid adoption of smart manufacturing is made possible by U.S.-Mexico linked supply chains (e.g., collaborative robots in Chihuahua's factories) [16].
- Economic vulnerability: Reliance on U.S. markets means global disruptions, like trade policy shifts, amplify local employment volatility [16, 21].
- Skill migration: Growth could be hampered by a lack of computer-based talent throughout Latin America, which is a critical barrier to harnessing the full benefits of automation and digital technologies [18, 22].

3.4 Institutional adaptation frameworks

Sustainable adaptation requires coordinated action:

- Collaboration between higher education institutions, industry, and government is essential to align training with evolving labor market needs [17].
- Lifelong learning and upskilling are critical, as emphasized by the World Economic Forum, especially in AI, data literacy, and resilience [22].

- Policy responses must address both the risks of labor exclusion and the need for inclusive access to new employment opportunities, as highlighted by ECLAC and OECD studies [18, 20].

3.5 Synthesis: Dual-pathway model for Chihuahua

This literature review supports a dual-pathway model:

- *Productivity-driven automation* enhances competitiveness but risks widening inequality unless accompanied by inclusive upskilling and social policies [5–9, 18–20, 22].
- *Adaptive labor ecosystems* require systemic collaboration to ensure the workforce can transition into emerging roles and industries [14, 16, 19, 20, 22, 23].

Chihuahua's context, marked by its industrial base, border location, and exposure to global trends, makes it a microcosm for understanding how automation, labor adaptability, and the future of work intersect in emerging economies.

4. Methodology: Diagnosing regional automation in Mexico

A mixed methods approach to survey these enterprises across the state of Chihuahua was used. As previously stated, a total of 152 companies were identified, with detailed information gathered on location, business structure, revenue, workforce size, and technological specialization. Data collection combined direct surveys, online research, and snowball sampling.

The primary aim of this study was to provide a detailed sectoral diagnosis of Chihuahua's automation ecosystem, prioritizing the identification of patterns, capacities, and structural challenges over inferential statistical analysis or predictive modeling. While illustrative tools as a linear regression between workforce size and billing and a sectoral breakdown of enterprise activity are included to support the descriptive narrative, these visualizations are intended to highlight empirical tendencies rather to establish causal relationships. The focus remains on capturing the empirical diversity and institutional dynamics shaping the region's transition toward Industry 4.0.

While nearly a third of the companies did not respond to direct inquiries (often due to confidentiality concerns), data were supplemented through web platforms (e.g., LinkedIn, Dun and Bradstreet). The final dataset reflects a comprehensive snapshot of the regional automation landscape.

5. Key findings on Chihuahua's automation sector

5.1 Geographical distribution and company structure

Most companies (66%) are located in Chihuahua capital, followed by Ciudad Juarez (26%). This distribution reflects the industrial infrastructure in the state and the binational manufacturing dynamics of the northern border.

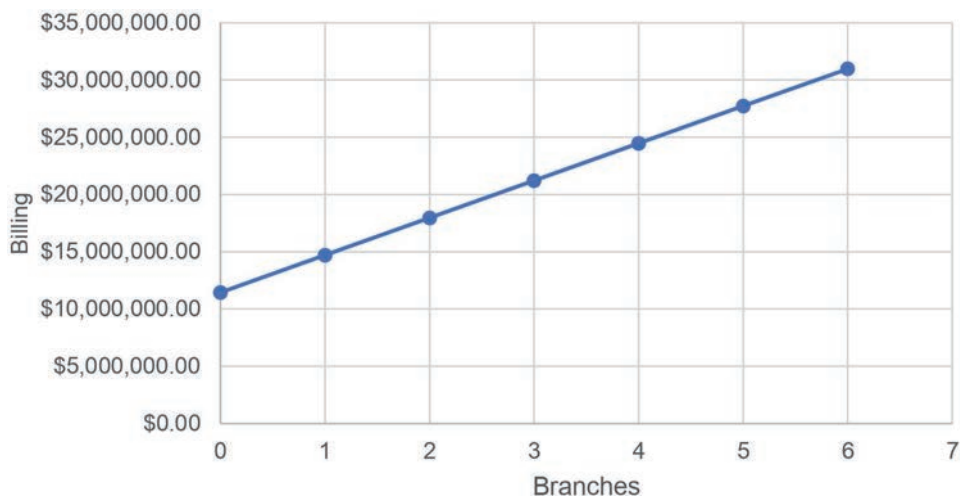


Figure 2.
Billing vs. branches.

The majority of enterprises are SMEs, with an average of 27 employees and 16 years in operation. Ownership structures are predominantly individual or small partnership-based, limiting access to investment capital.

Figure 2 illustrates the relationship between the number of company branches and annual billing. The linear trend suggests that firms with a broader operational footprint tend to generate higher revenue. Each additional branch is associated with an estimated billing increase of approximately \$3,255,721.73 Mexican pesos (\$162,786 USD), reinforcing the link between regional expansion and financial performance.

5.2 Economic activity and revenue levels

Revenue distribution is uneven. While 38% of companies report annual revenues of up to 10 million Mexican pesos (just over half million U.S. dollars), only 14% exceeded 31 million Mexican pesos (over one million and a half of U.S dollars). A significant 29% did not disclose financial data, suggesting limited transparency or informal practices.

To further illustrate the relationship between firm size (workforce and number of partners) and financial performance, **Figure 3** presents a linear model depicting the association between employees and billing. The model suggests a positive correlation, whereby each additional employee is associated with an estimated increase of approximately \$137,525.97 Mexican pesos (\$6876.29 USD) in revenue.

5.3 Business capabilities

The dominant areas of specialization include MRO (Maintenance, Repair, and Overhaul), PLC/HMI programming, and machinery automation. However, many companies engage in niche activities with limited market penetration. Only 43% have more than one branch, indicating a largely local operational scope.

Figure 4 provides a sectoral breakdown of the surveyed companies, highlighting the industrial diversity within Chihuahua's automation ecosystem.

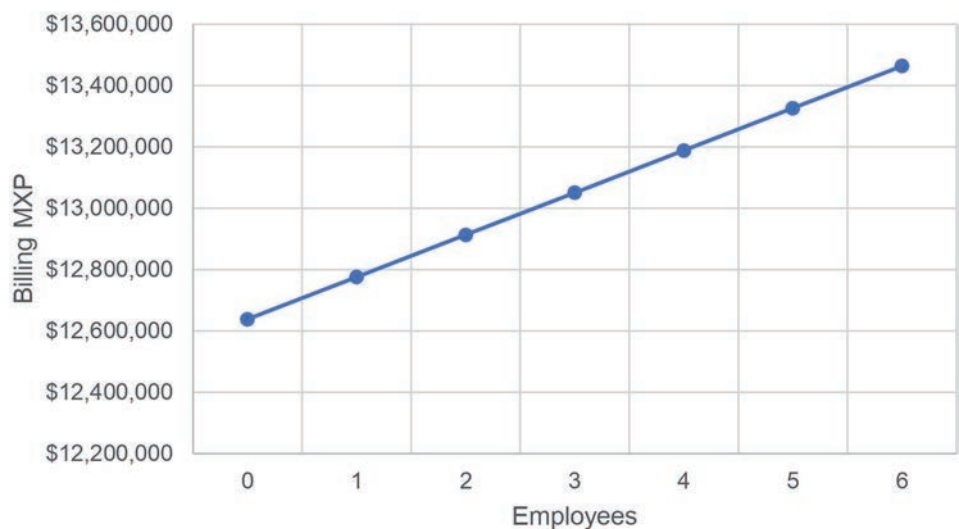


Figure 3.
Billing vs. workforce.

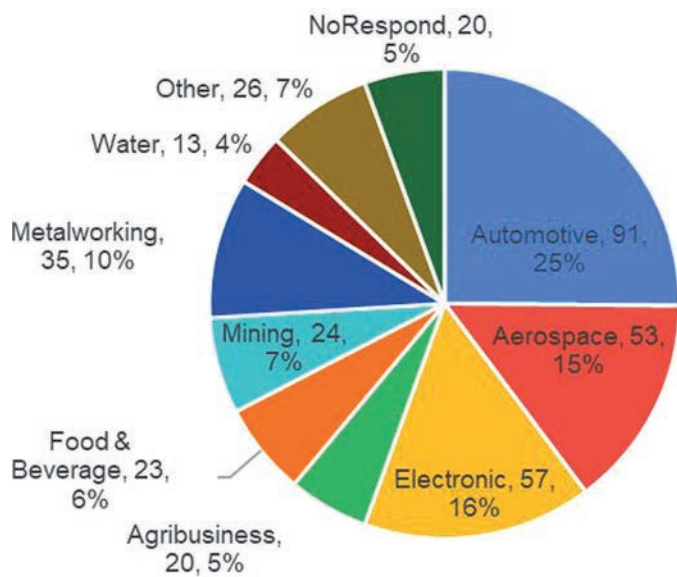


Figure 4.
Sectoral breakdown.

The automotive industry dominates with 25% of the sample, followed by electronics (16%) and aerospace (15%), underscoring the region's alignment with export-oriented, high-precision manufacturing. Other sectors such as metalworking, mining, food and beverage, and agribusiness are also represented, though to a lesser extent. This distribution reflects the specialization landscape shaping business capabilities, as well as the potential for cross-sectoral collaboration and cluster development.

5.4 Human capital and training gaps

Training needs are urgent. Over half of the companies (54%) identified technical training as a priority, followed by administrative upskilling (46%). Furthermore, interest in certifications is low, despite their importance for export readiness and global competitiveness.

The most requested certification was ISO 9001, though some firms incorrectly listed industry registration numbers, like IMMEX or Data Universal Numbering System (DUNS,) as certifications. This suggests the need for stronger guidance and support mechanisms.

6. Discussion: Regional automation, challenges, and policy recommendations

6.1 Clustering and market integration

Automation's clusters in Chihuahua are emergent but fragmented. Most firms operate independently, lacking the associative strength needed for economies of scale, joint innovation, or export consolidation. Creating local business networks, especially in Ciudad Juarez and cross-border zones (e.g., El Paso, TX and Las Cruces, NM), would enhance visibility and cooperation.

6.2 Skills mismatch and labor adaptability

Consistent with ECLAC's and OIT's warning [18, 19], there is a growing mismatch between workforce capabilities and the skillsets demanded by automation. Educational institutions must align curricula with industry needs, focusing on mechatronics, digital control systems, and data analytics.

6.3 Certification and market expansion

The relatively low interest in obtaining certifications among automation enterprises in Chihuahua poses a significant barrier to market expansion. As indicated by data obtained, only a small percentage of firms actively pursue international certifications such as ISO 9001, while others conflate certifications with industry identifiers like IMMEX or DUNS numbers. This conceptual ambiguity reveals a gap in business literacy regarding regulatory requirements for entering high-value global markets.

Certifications not only ensure compliance with international standards but also serve as strategic tools for gaining credibility, improving operational processes, and accessing supply chains in the aerospace, automotive, and electronic sector, all of which are prominent in northern Mexico. Without formal certifications, regional firms remain confined to domestic markets or low-complexity subcontracting roles.

To address this, a coordinated policy approach is needed. Public institutions can facilitate access to certification programs through subsidies, tax incentives, and technical assistance. Industry associations and clusters should also play an active role in disseminating information and providing peer-learning platforms.

In the broader Latin American context, ECLAC has also recommended certifications as a critical step toward improving firm productivity and competitiveness, particularly in digital and high-tech sectors [18]. Thus, integrating certification

strategies into the regional automation agenda is not optional; it is essential for sustainable growth.

6.4 Data governance and sector monitoring

A further challenge highlighted by the diagnostic is the absence of robust mechanisms for tracking sectoral development. Approximately 30% of firms did not provide complete data on core variables such as location, revenue, or policymaking, business support programs, and academic research.

Creating a unified, regularly updated automation sector database would allow policymakers, educators, and entrepreneurs to identify trends, monitor progress, and make informed decisions. Such a platform should include firm-level data (protected under privacy protocols), workforce profile, innovation capabilities, and supply chain linkages.

Moreover, a set of standardized indicators could be developed to assess sectoral health over time. Suggested metrics include:

- Average firm age and size
- Employment generation and skill distribution
- Export participation rates
- Certification levels
- Technology adoption (e.g., use of PLCs, robotics, AI systems)

6.5 Research limitations

While this study offers valuable insights into automation-driven enterprises in Chihuahua, several limitations should be noted. First, data gaps were evident, as approximately 30% of firms did not provide complete information, potentially biasing sectoral analyses. Second, the cross-sectional nature of the diagnostic limits the ability to assess longitudinal trends or causal relationships. Additionally, qualitative aspects such as worker experiences and informal sector dynamics were beyond the scope of this research. These limitations underscore the need for ongoing data collection, expanded sectoral coverage, and mixed-method approaches to deepen understanding and inform policy effectively.

Despite the noted limitations in data completeness and scope, developing these indicators remains crucial as they can both facilitate rigorous academic analysis and serve as benchmarks for enhancing regional competitiveness. To maximize their legitimacy and practical value, such initiatives must be pursued collaboratively, involving universities, industry representatives, and government agencies working together to overcome existing data challenges and build a robust inclusive monitoring framework.

7. Conclusions and policy implications

This study demonstrates that regional automation in Mexico, particularly in the state of Chihuahua, operates at the intersection of technological advancement

and socioeconomic constraint, based on an empirical diagnostic assessment of 152 automation-driven enterprises conducted in 2024. The findings, interpreted through four theoretical dimensions, explore the capacities of local enterprises shaping the Industry 4.0 transition in this border region. The analysis focused on identifying both the opportunities presented by automation and socioeconomic constraints influencing its integration into the future of work.

Visual evidence such as the observed positive correlation between human capital and income, as well as the concentration of firms in a few high-tech manufacturing sectors, reinforces the uneven distribution of productive capabilities and the relevance of targeted support strategies to address structural gaps and foster inclusive industrial development.

7.1 Technological disruption and industrial transformation

Chihuahua's manufacturing sector demonstrates increasing engagement with Industry 4.0 technologies, including robotics, digital control systems, and advanced data analytics. Firms are developing specialized competencies and show a readiness to adopt new paradigms, particularly as global supply chains shift and nearshoring intensifies. However, the scalability of these advances is limited by uneven access to technology and a lack of standardized certification pathways, especially for SMEs.

Key policy implications include education and training, to expand technical education and hand-on training programs in collaboration with universities and technological institutions to ensure a steady pipeline of talent skilled in automation-related fields like digital control systems, robotics maintenance, and data analytics. Collaboration with universities and technological institutes is vital.

7.2 Labor market polarization and skill gaps

Automation is accelerating labor market polarization, with rising demand for highly skilled technical workers and a decline in low-skill repetitive roles. Persistent gaps in workforce development, digital literacy, and access to affordable certification hinder the region's ability to adapt to these changes. This misalignment between employer needs and available skills threatens both firm competitiveness and worker inclusion.

The policy implication is to implement targeted initiatives to subsidize certification costs and increase awareness, particularly for SMEs and underrepresented groups, to promote inclusive workforce upskilling.

7.3 Border-region dynamics

Chihuahua's proximity to the U.S. border amplifies both opportunities and vulnerabilities. Cross-border technology transfers and integration with U.S. supply chains foster innovation but also expose the region to external shocks and intense competition for skilled labor. The lack of formal industrial clusters limits the region's ability to capitalize on these dynamics and to coordinate responses to shared challenges.

A significant policy would be to promote the development of formal cluster organizations in key cities such as Ciudad Juarez to enhance regional cooperation, facilitate innovation diffusion, and strengthen cross-border synergies.

7.4 Institutional adaptation frameworks

The effectiveness of automation as a driver of sustainable development depends on robust institutional frameworks. Current limitations in coordination among educational institutions, industry, and government agencies impede the creation of a resilient and adaptable regional ecosystem. There is also a need for improved data collection and monitoring to inform evidence-based policy and for governance structures that prioritize social inclusion.

A key recommendation would be to establish a permanent observatory or monitoring platform to track automation sector performance and support data-driven policymaking. Ensure that automation strategies address gender equity, small business participation, and intergenerational workforce integration to foster social cohesion alongside technological progress.

7.5 Summary

Chihuahua is a compelling microsystem where the interplay of automation, labor adaptability, and sustainable development is actively shaping the future of work. The findings underscore the importance of developing specialized manufacturing clusters supported by local firms with strong technological capabilities and flexible certification processes. Such clusters enhance regional competitiveness and responsiveness to evolving market demands. Furthermore, Chihuahua's strategic border location facilitates cross-border collaboration and knowledge exchange, which are critical for integrating into advanced manufacturing supply chains and capitalizing on nearshoring opportunities.

For less developed regions seeking to harness automation for inclusive growth, Chihuahua offers a valuable case study. There is a clear need to establish formal mechanisms for continuous workforce upskilling and innovation diffusion. Creating observatories or monitoring platforms to track socioeconomic impacts of automation could support evidence-based policymaking and adaptive governance, both essential for fostering an enabling environment for sustainable automation. These elements help mitigate labor market polarization and skill gaps while enhancing economic resilience and social cohesion aligned with environmental sustainability.

In conclusion, automation has the potential to drive sustainable and inclusive development in less developed regions if deliberate strategies are adopted to strengthen regional ecosystems. Aligning technological innovation with social equity and institutional adaptability will be essential to building a future of work that benefits all stakeholders.

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Chapter 4

Strategic Relational Human Resource Management in the Age of AI: Balancing Human and Technology Connections

Qian Zhang

Abstract

The increasing integration of artificial intelligence (AI) into human resource management (HRM) is reshaping workplace relationships and the strategic design of HRM systems. This book chapter examines the reciprocal influence between AI adoption and Strategic Relational Human Resource Management (SRHRM) systems, a framework that prioritizes HRM practices fostering positive workplace relationships and collective human and social capital emergence. This conceptual study employs a theory-building methodology to critically analyze how AI-driven HRM tools, such as algorithmic decision-making in recruitment, performance management, and promotion, contribute to sustainable competitive advantage through the effect on relational mechanisms like trust, fairness, and social connections. By integrating insights from strategic HRM, HRM digitalization, and human and social capital literature, this chapter develops a conceptual model depicting that organizations with strong SRHRM systems can strategically implement AI tools to align with relational values, ensuring technological advancements reinforce rather than impede human-centered HRM principles. The chapter advances theoretical understanding by reconciling fragmented perspectives on AI and relational HRM while offering practical guidance for designing AI-enabled SRHRM systems that balance operational efficiency with sustainable workplace relationships.

Keywords: strategic human resource management (strategic HRM), artificial intelligence (AI), positive workplace relationship, relational HRM, human-AI relationship, sustainable competitive advantage

1. Introduction

The rapid advancement of artificial intelligence (AI) is transforming human resource management (HRM) by introducing new opportunities and challenges in how organizations manage workplace relationships. This chapter follows Kellogg et al.

[1] to define AI and algorithmic technologies as “computer-programmed procedures that transform input data into desired outputs in ways that tend to be more encompassing, instantaneous, interactive, and opaque than previous technological systems” (p. 366). AI-driven tools, such as automated video recruitment, algorithmic performance evaluations, and predictive HRM analytics, are increasingly being adopted to enhance efficiency and decision-making quality in HRM processes [2–4]. However, as these technologies reshape traditional HRM systems and practices, their impact on relational mechanisms and outcomes, such as trust, fairness, and social connections, remains a critical area of exploration. Therefore, this chapter, through a theory-building methodology, first explains the reciprocal influence between AI adoption and Strategic Relational Human Resource Management (SRHRM). It then provides an AI-enabled model of SRHRM to facilitate firm sustainability.

SRHRM, an interrelated set of HRM practices that foster positive workplace relationships and collective human and social capital development [5, 6], emphasizes the importance of employees’ ability to relate (i.e., relational knowledge, skills, and abilities) in designing the practices [5, 6]. It highlights that relational mechanisms such as trust, collaboration, and positive workplace relationships are key drivers of organizational success and sustainable competitive advantage [6]. However, the integration of AI into strategic HRM requires that SRHRM systems need to be adapted and advanced for their use in the digital age. To explain, this AI integration presents a paradox: while it can streamline operations and reduce biases, it may also undermine equity and relational outcomes if not designed strategically and implemented carefully. For instance, algorithmic decision-making in promotions or performance management could enhance transparency but may also erode employee trust if perceived as impersonal or opaque [7]. Thus, understanding how AI adoption interacts with SRHRM principles is essential for ensuring that technological advancements complement, rather than displace, the human elements of HRM principles and processes.

This chapter critically analyzes the reciprocal relationship between AI and SRHRM systems, exploring how organizations can strategically deploy AI to reinforce relational HRM outcomes for sustainable competitive advantage. Grounded on recent theoretical advancements in strategic HRM and HRM digitalization literature, this chapter highlights both the risks and opportunities of AI integration in shaping workplace relationships. Furthermore, it provides insights into designing a model of AI-enabled SRHRM systems that balance efficiency with the preservation of human-centered values, ultimately contributing to firm sustainability. The implications help guide HRM professionals and organizational leaders in navigating the complexities of AI integration while maintaining a focus on fostering positive workplace relationships.

In sum, this chapter addresses three critical gaps in the strategic HRM and HRM digitalization literature. First, while existing research extensively examines AI’s operational efficiencies in HRM (e.g., automated recruitment, predictive analytics), it largely overlooks how algorithmic systems reshape the relational dimensions of organizations, specifically, the erosion of trust, collaboration, and social capital when AI mediates workplace interactions [2, 7]. Second, though strategic HRM scholars recognize relational mechanisms as microfoundations of competitive advantage [5], current frameworks fail to adapt these principles to AI-augmented work contexts, leaving a void between technology-driven HRM practices and the human-centered values underpinning SRHRM systems. Third, while sociotechnical systems theory emphasizes balancing technical and social systems [8], prior studies mainly adopt a technology-centric view of AI integration, neglecting stakeholder cocreation and

participatory design as means to align algorithmic transparency with relational accountability [9]. By bridging these gaps, this chapter advances a novel AI-enabled SRHRM model that repositions AI as a relational stakeholder, not just a tool or a mechanism, and introduces five adaptive strategies, from inclusive relational KSAs to hybrid human-AI practice design, to sustain workplace relationships in the digital age. In doing so, it challenges the prevailing transactional paradigm of AI-HRM integration and offers a pathway to reconcile technological advancement with the social and relational infrastructure vital for organizational resilience, especially needed in an era of rapid technological change.

2. SRHRM in the age of AI

The SRHRM model advances traditional HRM systems by placing individuals' relational knowledge, skills, and abilities (KSAs) at the center of strategic human capital development rather than simply encouraging interpersonal interactions or focusing on employee job-specific competencies [5]. Grounded in the multilevel micro-foundational framework, SRHRM views individual employees, rather than their units (e.g., departments, teams), as the key agents in building and maintaining workplace relationships [5, 6]. SRHRM systems include a coherent set of HRM practices, including strategic relational recruitment and selection, training and development, performance appraisal, compensation and rewards, promotion, job design, participation and involvement, and relational events—all strategically designed to foster relational KSAs. These individual-level competencies serve as the microfoundations for building unit-level human and social capital. As employees build high-quality internal and well-extended external relationships, they create social capital that enhances human capital for collective performance, which contributes to inimitable firm resources (i.e., competitive advantage).

Specifically, SRHRM systems enable organizations to benefit from the relational outcomes of individuals (social capital) and convert them into valuable, firm-specific collective resources. Employees' relational KSAs, as a specific type of human capital, help form useful social networks and connections that enhance relational coordination, communication, and knowledge exchange within and across organizational boundaries [10, 11]. These interpersonal mechanisms further enhance individual and unit-level learning, adaptability, and innovation, which are essential in rapidly evolving business environments for sustainability [11]. SRHRM has been found to strengthen workplace relationships among employees and between employees and managers, improve operational efficiency, enhance talent attraction and retention, and ultimately contribute to firms' financial outcomes [5].

In the rapidly evolving landscape of HRM digitalization, social capital and workplace relationships have emerged as critical differentiators that sustain competitive advantage where technology alone falls short. While AI transforms HRM through data-driven efficiencies in recruitment, performance management, and workforce analytics, it can potentially damage firms' competitive advantage by having competitors easily implement the same AI tools or increasing the risk of leaking important data [7]. In these cases, it is the relational foundations of firms that prevent their competitive advantage from algorithmic replication and digital attacks. The complex webs of trust, shared norms, and collaborative networks that constitute social capital generate value precisely through their contextual embeddedness and social complexity [12]. The relational foundations that create the mechanisms and dynamics where

organizations most effectively leverage AI are those that simultaneously invest in firms' relational structure [13] as they recognize that algorithmic systems achieve full potential only when integrated with human-centered HRM systems. Additionally, the resource-based view clarifies this advantage: while competitors may purchase the same AI tools, the socially complex processes of knowledge-sharing, adaptive learning, and creative problem-solving that emerge from strong workplace relationships remain uniquely difficult to imitate (i.e., competitive advantage) [5, 14].

However, it is worth noting that the integration of AI into HRM systems may also introduce challenges that threaten to hinder the social capital that organizations require to thrive. For instance, algorithmic management systems risk creating perceptions of opacity and unfairness when employees fail to understand automated decisions about promotions, compensation, or development opportunities [7]. In addition, this AI integration has greatly transformed traditional patterns of employee interaction from human-to-human collaboration to human-to-machine engagement [2–4]. As AI systems increasingly perform personnel-related tasks such as decision-making, HR analytics, internal communication (e.g., chatbots), and feedback provision, employees are more frequently interacting with nonhuman agents in their work processes. While this shift enhances work efficiency, it disrupts the social elements of work by depriving employees of the interpersonal interaction that typically occurs between coworkers [3]. Moreover, the relationship between employees and AI agents can be complicated, as these systems are sophisticated by design and function [15]. On one hand, some employees view AI agents as inauthentic by shifting the workplace toward more of an “asocial system,” where people may feel socially disconnected at work [15]. For example, in cases where supervisors have one-on-one meetings with employees for performance reviews or where employees consult their coworkers for opinions, AI agents can offer information and feedback in a more timely and effective manner. However, AI agents are deficient in terms of providing an engaging and socially rich user experience, such as heartwarming interpersonal communications. On the other hand, some employees may perceive these AI systems as “social agents” with whom they form affective bonds and treat them as “machine coworkers” or even “algorithmic friends” because they are designed to function as autonomous and intelligent work partners [3, 16].

Research based on the social affiliation theory shows that frequent AI interaction activates employees' intrinsic need for social connection [3]. In some cases, this may stimulate their adaptive behaviors, such as helping coworkers to reestablish a sense of belonging. However, it can also lead to employees' maladaptive behaviors, such as heightened loneliness, which impairs their well-being and spills over into after-work life through increased insomnia and alcohol consumption [3]. Thus, the replacement of human interactions with chatbots and automated evaluations may gradually diminish the quality of workplace relationships that underpin effective work collaboration, organizational commitment, and extra-role behaviors. These risks call for attention from HRM scholars and practitioners to design an AI-enabled HRM model that actively strengthens social capital.

SRHRM systems, therefore, need to be advanced and adapted to address these emerging relational challenges to promote positive workplace relationships in AI-augmented environments. The traditional SRHRM framework focuses on designing HRM practices that foster high-quality interpersonal relationships as a strategic resource [5, 6]. To remain effective in the era of AI, SRHRM needs to extend its relational foundation and conceptualization to account for the potential social deficits introduced by human-AI interactions. This includes implementing adapted

SRHRM practices that proactively cultivate AI-human trust and communication as well as mutual understanding. In essence, SRHRM systems need to shift from solely managing human-to-human relationships to filling the relational voids created by the increased presence of AI “coworkers.” In doing so, SRHRM systems can help restore the socially thriving and engaging workplace that traditional interpersonal interactions once provided.

Moreover, advancing the SRHRM framework to meet the relational needs of employees in AI-enabled work contexts is critical for long-term organizational sustainability. As the psychological and behavioral outcomes of AI usage on employees become more apparent, ranging from increased helping behaviors to burnout and withdrawal [3, 7, 17], organizations need to advance their HRM strategies that promote resilient and socially connected workforces. By providing HRM configurations and fostering the contexts where relational capacities are intentionally built and maintained with the inclusion of AI agents, SRHRM systems can mitigate the risks of social isolation and support employee well-being and performance. In turn, this relational resilience not only enhances individual and collective human and social capital but also strengthens the firm’s adaptive capacity in an era of rapid technological change.

This chapter proposes that firms’ sustainable competitive advantage in the AI era comes not from choosing between technological and relational advancement, but from strategically architecting their symbiosis. AI systems excel at identifying patterns in personnel data and optimizing analysis processes, while workplace relationships enable the interpretation, contextualization, and implementation of these insights in ways that create strategic value for sustainable competitive advantage. For example, predictive HRM analytics might flag turnover risks with precision, but only skilled managers who know how to best apply their relational KSAs can convert this information into effective retention strategies. This complementarity reflects core principles from sociotechnical systems theory, which emphasizes that the most effective organizational functioning requires the joint optimization of technical and social systems [8]. In practice, firms can achieve this balance by implementing AI-enabled SRHRM systems that, for example, augment rather than automate human judgment, use people analytics to strengthen rather than control teamwork, and design digital platforms that facilitate rather than hinder high-quality social connections and communication. These practices will lead to ideal outcomes of sustainable competitive advantage that are embedded in firms’ ability to benefit from AI’s analytical power while cultivating the relational foundations necessary for innovation, agility, and resilience in turbulent business environments. The next section of the chapter elaborates on an AI-enabled model of SRHRM systems.

3. Methodology

This paper follows a large stream of conceptual papers in the field of HRM studies (e.g., [18–20]). It employs a theory-building methodology grounded in a thorough literature review and critical analysis to advance a novel framework for SRHRM in the AI era. Specifically, the research process followed three iterative phases: (1) problem identification, where key tensions between AI-driven HRM efficiencies and relational outcomes (e.g., algorithmic opacity eroding trust, human-AI interaction displacing social connections) were mapped through analysis of seminal works across strategic HRM, HRM digitalization, and social capital literature; (2) problematization,

critically examining paradoxical interactions between AI systems and relational mechanisms to identify gaps in extant HRM digitalization models; and (3) theory bridging, integrating fragmented perspectives from sociotechnical systems theory, relational bureaucracy, and algorithmic management to establish a multilevel, comprehensive conceptual model.

The methodological innovation of this study lies in its relational approach to socio-technical design principles. Unlike prior AI-HRM frameworks prioritizing technical optimization, this research reconceptualizes AI as a relational stakeholder rather than a simple tool. By applying social capital theory as an analytical lens and theorizing how algorithmic systems reshape relational mechanisms such as trust, social networks, collaborative norms, and relational coordination, the study pioneers a human-centered view of transactional AI integration paradigms. This approach uniquely positions workplace relationships as a strategic infrastructure that can positively impact AI's effect on organizational and individual outcomes. By doing so, it shifts the debate and conversation from "how AI replaces HRM practices" to "how AI augments relational resilience" in the organizational context.

The research methodology further innovates through stakeholder-centered design logic. Where conventional AI-HRM research often adopts a technology-focused perspective, this study embeds multistakeholder cocreation as a core mechanism for reconciling AI efficiency with relational values. By synthesizing emerging evidence on participatory algorithm design (e.g., [7, 9]) and relational coordination theory [10, 13], the model conceptualized in this chapter advances the ideology of transparency-as-process rather than transparency-as-output, requiring continuous stakeholder involvement between HRM professionals, employees, data scientists, and regulators. This advancement transforms AI implementation from technical deployment to relational discussion.

The methodological rigor of the chapter was ensured *via* triangulated theoretical validation: (a) cross-disciplinary consistency checks between HRM, computer science, and organizational sociology literatures; (b) application of seminal theories from resource-based view and microfoundations theory in the strategic management literature to ensure multilevel coherence of theoretical conceptualization; and (c) theoretical assessment on documented AI integration failures (e.g., bias amplification in recruitment algorithms) in the HRM digitalization literature. While empirical testing lies beyond this conceptual phase, the methodology explicitly generates a testable conceptual model of AI-enabled SRHRM systems for future validation. The AI-enabled SRHRM model thus represents a theoretically novel, stakeholder-grounded architecture for sustainable HRM digitization to fill the void in the extant literature.

4. An AI-enabled model of SRHRM systems

The increasing integration of AI and algorithmic systems into HRM functions reshapes employees' work-related interactions and, in turn, their workplace relationships [1–3]. Many algorithmic systems are designed to minimize subjective human judgment and automate decision-making, such as algorithmic recruitment and performance analytics. Although these AI-enabled tools can enhance efficiency and decrease bias, they risk eroding trust, transparency, and social capital by depersonalizing HRM processes and inadvertently decreasing opportunities for employees' relational engagement in the workplace. This concerning influence calls for urgent

attention from HRM scholars and practitioners, as individuals influenced by algorithmic HRM decisions often lack power and can only be passively impacted by such automation. Yet, these decisions can profoundly influence their daily work experiences, such as through algorithm-driven scheduling and task assignment from gig platforms, as well as their long-term career trajectories, including promotions and development opportunities [7, 9, 18].

As AI continues to transform how work is organized and experienced, the SRHRM framework needs to expand its focus from traditional human-to-human relationships to human-to-machine hybrid relationships, which involve important stakeholders who can influence the design and implementation of algorithmic HRM systems as well as those who are influenced by these systems [7, 9]. In other words, to strengthen and promote organizational sustainability through AI-facilitated workplace relationships, SRHRM systems need to evolve into dynamic, relational ecosystems that foster synergistic human-AI collaboration. This transformation requires AI to augment human capital and social capital.

The AI-enabled model of SRHRM systems requires embedding social capital theories into the design and implementation of HRM functions. This is to ensure technology strengthens relational mechanisms such as trust and collaboration. The model prioritizes five core adaptations based on the original SRHRM framework (as in [5]): (1) inclusive relational KSAs, which extends the traditional definitions to include individuals' attributes to understand and relate to AI algorithms for social relationship maintenance in digital era; (2) transparent cocreation of AI systems, where key stakeholders (e.g., employees, leaders, HRM professionals, data scientists) collaborate to design explainable and fair algorithms that mitigate bias and build AI-human trust; (3) hybrid human-AI HRM practice design, which promotes critical social interactions while automating routine tasks; (4) relational analytics, which use AI to map and strengthen social networks, identify collaboration opportunities within and across unit boundaries, and measure employees' relational health and well-being; and (5) AI-adaptive relational culture, which fosters inclusive value to proactively address the social and psychological challenges of AI integration, such as algorithm aversion, digital disconnection, and workplace alienation.

First, an AI-enabled model of SRHRM necessitates redefining relational KSAs to incorporate AI-specific relational capacities. These attributes enable employees to effectively understand, interpret, and respond to AI tools while maintaining critical workplace relationships. The original SRHRM framework facilitates the development of robust social networks built on trust and shared understanding through individuals' relational KSAs, which further foster collective human and social capital emergence and the alignment of individual efforts with strategic goals. These social structures enhance a firm's ability to respond to change, utilize strategic human capital, and embed resilience into its operations and functioning. However, traditionally defined relational KSAs are insufficient for addressing relationship-building in AI-augmented work settings. An advanced SRHRM model needs to first expand the conceptualization of relational KSAs to fit with the AI context. This new inclusive set of individual attributes encompasses, but should not be limited to, algorithmic awareness (understanding how AI-driven decisions are made and their implications for social interactions in the workplace), digital empathy (the ability to navigate AI-mediated relationships with emotional intelligence), and cross-boundary coordination (effectively collaborating across human and nonhuman (i.e., AI) actors to sustain relational cohesion). By integrating these new dimensions, organizations can foster a workforce capable of balancing technological efficiency with the complexities of human connection.

Second, for an AI-enabled model of SRHRM to be effective, it needs to ensure adequate levels of transparency by strategically engaging key stakeholders throughout both the design and implementation stages. Prior research has highlighted the important role of stakeholder involvement in shaping the success of algorithm-based HRM practices [4, 7, 18]. While algorithmic opacity can protect firms' intellectual capital and prevent competitors from easy imitation—thus preserving competitive advantage—it also poses significant risks. Chief among these is the potential erosion of trust among AI users, including employees and job candidates, who may perceive decision-making processes as unfair [4, 7]. This concern becomes especially salient when AI-enabled HRM systems influence important outcomes, such as employees' career trajectories, particularly given that few employees have the expertise to understand how these systems operate [2].

To address these concerns, scholars have advocated for a more intentional alignment between the degree of algorithmic opacity and a firm's strategic objectives. Where the risks of opacity outweigh the benefits, firms should consider adopting certain tools and practices that improve transparency [4, 7]. Within an AI-enabled SRHRM model, it is therefore essential to meaningfully involve a broad range of stakeholders—including system users, individuals affected by algorithmic decisions, and those responsible for deploying such systems—to ensure outputs are interpretable, aligned with organizational strategy, and compliant with legal and ethical standards [4, 7].

Reducing algorithmic opacity and promoting transparency requires more than technical solutions; it also calls for strategic human roles, especially that of the HR department. For instance, HR managers can serve as explainers and sustainers of algorithm-based systems, helping translate system logic into accessible, actionable terms for employees and other stakeholders [1, 7]. It is worth noting that opaque algorithms, if left unchecked, may undermine perceptions of fairness, especially when decisions lack explainability or meaningful human oversight [4, 7, 9]. To mitigate these risks, the AI-enabled model of SRHRM systems needs to aim for achieving a balance between technological efficiency and relational accountability. One solution, as suggested by Langer and König [7], involves embedding explainable AI principles—where algorithms generate interpretable justifications for HRM decisions such as hiring or promotion—and fostering hybrid human-AI collaboration, ensuring automated processes are augmented with human judgment. **Figure 1** shows an example model of AI-enabled SRHRM systems, which focuses on stakeholder involvement, transparency promotion, and balanced relational perspectives. By strategically prioritizing transparency, organizations can better address stakeholder concerns, create AI trust, and realize the strategic advantages of AI-enabled SRHRM.

Third, AI-enabled SRHRM systems require strategic integration of human-AI collaboration into their configuration. Specifically, not only do SRHRM practices need to be systematically designed, accurately interpreted, and collaboratively implemented by humans and AI, but also these practices should evolve to leverage AI as a relationship-enhancing tool, including both human-to-human and human-to-AI relationships. In essence, a critical adaptation lies in the redesign of SRHRM practices to leverage AI as a tool for enhancing, rather than replacing, workplace relationships. This adaptation reflects a relational configuration of the interrelated SRHRM practices.

For each SRHRM activity, although there is a variety of possible development strategies regarding algorithm-based systems to support or automate HRM activities [2, 7], it needs to be strategically designed as one piece of the integrated AI-enabled

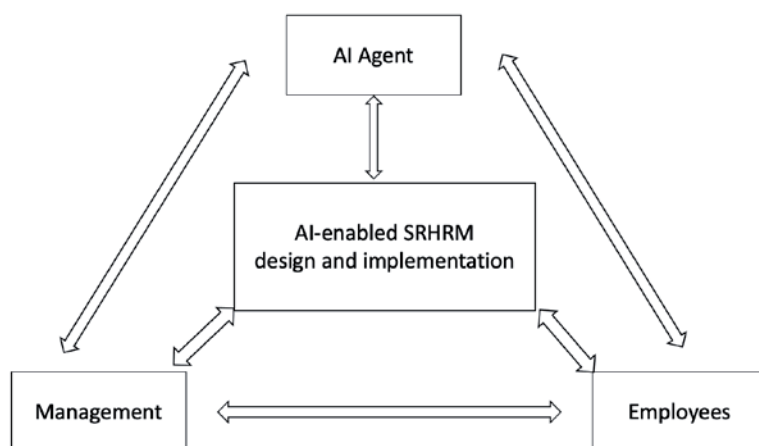


Figure 1.
A relational model of AI-enabled SRHRM systems.

SRHRM configuration. For instance, recruitment and selection processes can be redesigned to assess candidates' capabilities to work collaboratively with AI tools, not just with people. Recruitment practices also need to deploy AI to reduce bias in hiring (e.g., fair resume screening, structured selection process), but pair it with onboarding practices, particularly structured relationship-building initiatives. To explain, AI can help match new hires with mentors based on shared interests and goals, while chatbots provide real-time support, freeing HR professionals for meaningful onboarding conversations.

Training and development practices should evolve to enhance both interpersonal skills and digital relational literacy, such as emotional intelligence in virtual contexts and ethical interaction with algorithmic systems. Moreover, AI systems can be utilized to personalize skill-building (e.g., recommending strategically targeted training courses or professional development workshops). They can also be used to suggest and design social learning activities, such as AI-knowledge-sharing challenges that incentivize AI-human collaboration. Moreover, AI systems can offer managers valuable information, such as when to train and how to train their employees in a relational manner. Platforms (e.g., Degreed) have already combined machine learning with certain social features to foster relationship enhancement [21].

For performance management, for example, traditional annual reviews need to be replaced with AI-driven continuous feedback systems that analyze individual contributions, peer recognition, and collaboration patterns. Additionally, it is better to supplement these insights with facilitated structured development dialogs, where managers use AI-generated data to engage in developmental conversations rather than simply relying on algorithmic messages. In other words, feedback and appraisal systems should retain human elements that support relationship development while using AI-generated insights as a complement rather than a replacement. This is to ensure employees feel heard and valued and are kept embedded in a socially rich work context.

Moreover, AI-powered SRHRM systems can also facilitate new forms of participation and involvement, where employees codesign algorithmic systems, ensuring that relational values such as empathy, fairness, and psychological safety are embedded in how these tools operate.

In addition, AI-enabled SRHRM systems can include practices that focus on employee well-being. For example, predictive analytics can be utilized to identify employees' burnout risks (e.g., changes in communication patterns), but complement these alerts with relational solutions, such as team recalibration or supportive social check-ins. Similarly, talent mobility programs can also be added. AI can identify internal candidates for roles, but sustainability requires fostering cross-functional relationships through AI-facilitated innovation hubs where employees from different departments solve problems together, building networks that outlast any single project.

These adaptations align with sociotechnical systems theory, which emphasizes that optimal HRM requires harmonizing technical capabilities with social dynamics [8]. In practice, firms like IBM and Unilever have exemplified this balance, using AI tools for data-driven HRM insights while investing in transparency measures (e.g., ethics boards, manager training) to maintain trust.

Fourth, AI-enabled SRHRM systems must embed *relational analytics* as a core capability to support and sustain the social richness of the organization. Leveraging AI-driven analytics, organizations can identify critical relational patterns, such as collaboration gaps, communication bottlenecks, or burnout risks among employees. For instance, AI-powered network analysis can detect isolated individuals or overloaded "knowledge brokers." Accordingly, it should prompt timely and targeted interventions such as mentorship programs, team restructuring, or workload redistribution. In addition, sentiment analysis embedded in feedback systems can help assess relational health by capturing emotional tone, trust levels, or signs of conflict within teams. Beyond diagnosis, AI can also generate data-informed recommendations for relational interventions (e.g., team-building activities or leadership coaching) designed to strengthen social capital [10]. By treating workplace relationships as measurable and optimizable assets, AI-enabled SRHRM aligns predictive capabilities with the human dynamics that underpin innovation, adaptability, and long-term retention.

Lastly, AI-enabled SRHRM systems should play a critical role in mitigating the alienating effects often associated with algorithmic management by embedding ethical, inclusive, and relationally grounded values into the design and deployment of AI technologies. For instance, AI-enabled feedback tools can promote inclusive dialog by anonymizing inputs to reduce bias in performance evaluations, while adaptive learning platforms can personalize development opportunities in ways that respect diverse needs and learning styles. AI can also help monitor and flag early signs of exclusion or inequity in team dynamics, such as imbalances in speaking time during virtual meetings, enabling timely managerial intervention.

The AI-enabled model of SRHRM systems strategically directs technology advancement toward enhancing relational value and ensuring such values remain central. It encourages organizations to view AI not only as a tool for efficiency but also as a partner in sustaining a human-centered workplace [22, 23]. For example, AI-driven scheduling systems can be designed to support work-life integration by accounting for caregiving responsibilities, while chatbots can be programmed to direct employees to mental health resources or peer-support networks, thereby reinforcing a culture of care and belonging. Ultimately, firms that can seamlessly integrate SRHRM practices with AI technologies will be better equipped to foster collaboration, sustain trust, and promote innovation in increasingly hybrid and complex work environments, where social and technical systems are not only coexisting but fundamentally coevolving.

In sum, an AI-enabled model of SRHRM systems represents more than just a traditional HRM infrastructure but a strategic configuration for building enduring organizational capacity and achieving long-term sustainability in an AI-augmented economy. As AI technologies become increasingly embedded in core HRM functions, SRHRM offers an important relational lens to ensure these tools serve not only efficiency goals but also ethical, inclusive, and human-centered outcomes. To do so, AI-enabled SRHRM systems target beyond regulatory compliance by adopting proactive strategies that align AI capabilities with organizational values. This includes conducting algorithmic audits to detect and mitigate bias, involving employees in the cocreation of AI tools to enhance acceptance rate and trust, and implementing AI literacy initiatives that empower all stakeholders to critically engage with algorithmic decision-making [7, 18]. Moreover, organizations should strategically navigate complex trade-offs, such as balancing transparency with intellectual property protection or deterring the manipulation of algorithmic systems, as seen in gig economy platforms.

When implemented effectively, AI-enabled SRHRM systems can foster relational resilience—the ability to sustain high-quality workplace relationships amid ongoing technological and market disruptions. Leading firms like Siemens have illustrated this approach by using AI technologies to monitor team dynamics while simultaneously training managers to interpret relational data in ways that reinforce trust and psychological safety. This human-technology partnership creates a durable competitive advantage: while AI optimizes routine processes, humans focus on meaning-making, creativity, and the social cohesion that machines cannot replicate. Ultimately, the future of strategic HRM lies in this coevolution of technology and workplace relationships, where data-driven insights and relational intelligence converge to build organizations that are not only adaptive and efficient but also deeply human-centered [22].

5. Discussions

In today's AI-augmented work environments, the need to cultivate positive workplace relationships is more critical than ever. SRHRM systems offer a timely framework to meet this challenge. As AI increasingly emphasizes its advancement in automating technical, repetitive, and data-intensive tasks, it is the uniquely human capabilities, such as the ability to collaborate, empathy, trust-building, and contextual judgment, that emerge as key drivers of organizational differentiation and resilience. An AI-enabled model of SRHRM systems responds to this shift by advancing its design and implementation to better fit the AI context and facilitate firms' sustainable competitive advantage.

The AI-enabled model of SRHRM systems offers an important configuration of HRM systems, which positions workplace relationships, not just algorithms, at the center of organizational strategy in the digital era. By embedding principles of social capital theory into the design and implementation of HRM functions, this model ensures that technological advancement reinforces, rather than erodes, the relational mechanisms (e.g., trust, collaboration, and mutual respect) that sustain organizational performance [5, 8, 9, 11]. Unlike conventional AI-integrated HRM approaches that often treat technology as a substitute for human judgment, the AI-enabled SRHRM model advances a more strategically socially intelligent integration. It does so by introducing five critical adaptations: inclusive relational KSAs that

encompass human-AI understanding, stakeholder cocreation to promote algorithmic transparency and trust, hybrid human-AI design that ensures and sustains key social interactions, relational analytics that measure and enhance relational well-being, and an AI-adaptive culture that addresses the emotional and psychological dimensions of AI integration.

These adaptations are not only necessary but urgent. As organizations confront growing concerns about algorithmic opacity, digital disconnection, and AI-induced workplace alienation, the AI-enabled SRHRM model offers a solution to the relational resilience of individuals and organizations. Firms that adopt this model are better equipped to maintain human connection in technologically saturated environments, enabling them to benefit from the efficiency of AI without sacrificing the social infrastructure that supports learning, knowledge-sharing, well-being, and innovation. Ultimately, this model reframes AI not as a threat to relational HRM but as a catalyst for reimagining it. It enables HRM systems to evolve in ways that are both technologically advanced and deeply human. In doing so, the conceptual model of this study lays the foundation for sustainable, inclusive, and ethically grounded organizational futures.

Developing an AI-enabled model of SRHRM systems offers significant theoretical contributions by rethinking the role of AI in HRM through a relational lens. This model bridges foundational HRM theories with emerging discourses on AI and sociotechnical systems. By integrating social capital theory with algorithmic management research [1, 7, 10], it underscores that while AI enhances efficiency, social capital that is embodied in trust, collaboration, and shared values remains an irreplaceable strategic asset. The model challenges the dominant transactional perspective of AI in HRM design, which focuses primarily on automation, by repositioning AI as a *relational amplifier* that augments, rather than replaces, human judgment. It also extends sociotechnical systems theory [8] by illustrating how HRM systems dynamically align technological capacities (e.g., predictive analytics, AI explainability) with evolving social processes (e.g., relational cocreation, relational cultural adaptation). Furthermore, the model advances strategic HRM literature by showing that AI, when designed through a relational lens, contributes not just to operational efficiency but to the cultivation of sustainable human capital, especially through inclusive relational KSAs, stakeholder-driven AI design, and relational analytics. Overall, this model offers a new theoretical architecture for understanding how AI-human complementarities can enhance relational resilience and innovation in the digital age.

Practically, the AI-enabled SRHRM model offers a strategic redesign of HRM systems, which ensures that AI integration enhances relational dynamics and promotes sustainable organizational capacity. First, organizations should adopt particular AI principles (e.g., explainable AI) in HRM decisions, particularly in areas like recruitment, performance evaluation, and promotion, where clarity and fairness are critical for trust-building. For instance, AI tools that offer transparent rationales for HRM decisions (e.g., highlighting the key attributes in a candidate's profile) can reduce perceptions of algorithmic bias and promote equitable outcomes. Second, HRM practices should be redesigned through a *hybrid human-AI model*, where AI handles routine, data-intensive tasks (e.g., initial resume screening or scheduling), while human actors focus on high-touch relational activities such as onboarding, mentoring, or conflict resolution. Third, organizations should leverage *relational analytics* to proactively monitor and improve the social fabric of work, such as by using AI-powered network

analysis to detect isolated employees, identify overburdened knowledge brokers, or measure team sentiment in real time. Fourth, firms should cultivate an *AI-adaptive relational culture* that supports digital trust, psychological safety, and inclusion, particularly as AI introduces new challenges such as algorithm aversion attitudes or digital disconnection perceptions. Finally, embedding *inclusive relational KSAs*, including AI literacy and human-AI interaction skills, into training and development ensures employees are prepared to navigate increasingly complex social-technical systems. Together, these practices enable organizations to align AI adoption with relational goals, ensuring that technological advancements strengthen rather than weaken the human foundations of work.

Pioneering firms have begun to illustrate how transparent and participatory AI-enabled HRM configurations can preserve, and even enhance, relational quality in the workplace. For example, IBM's implementation of AI-driven talent management systems paired technology with ethics review panels and manager training programs focused on trust-building. This leads to both operational gains and measurable improvements in social capital. These outcomes reflect broader strategic HRM research that shows organizations achieve superior performance when digital capabilities are integrated with robust relational mechanisms.

However, the implementation of AI-enabled SRHRM systems also raises important ethical and strategic challenges. Ethically, firms need to navigate tensions between transparency, privacy, and proprietary protections—especially when AI systems process sensitive employee data [4, 7]. Practices such as algorithmic audits and employee feedback loops can enhance accountability but require being designed to avoid unintended consequences, such as metric manipulation or algorithm gaming. Strategically, the success of AI integration depends on contextual alignment with factors like organizational culture, industry dynamics, and workforce characteristics. For example, while gig economy platforms may prioritize algorithmic optimization, knowledge-based firms may benefit more from AI-augmented collaboration tools that reinforce team cohesion. In all cases, HR leaders should emphasize AI literacy across the workforce, equipping both employees and managers to critically interpret and ethically engage with AI outputs. By proactively addressing these considerations, organizations can build AI-enabled SRHRM systems that not only deliver efficiency but also foster resilient and positive relationships in workplaces, positioning themselves for sustained success in a digital world.

6. Limitations and future research directions

Despite its contributions, this conceptual study has several limitations that deserve scholarly attention. First, while the proposed AI-enabled SRHRM model has theoretical and practical insights, its conceptualization remains empirically untested. Future research should empirically examine the framework through rigorous studies, such as using case analyses of firms implementing relational AI-HRM systems or longitudinal surveys measuring how AI transparency impacts trust and collaboration. Second, the model primarily focuses on formal organizational settings, which potentially overlooks nuances in gig economies or decentralized work structures where algorithmic management dominates [24]. Third, the framework is conceptualized based on the assumption of organizational willingness to prioritize relational outcomes alongside efficiency. This is grounded

on the theoretical analysis for sustainable competitive advantage generated by the cocreation of human and social capital [5, 6]. However, this assumption may not align with the short-term profit motives of organizations in certain industries. Finally, the ethical tensions between algorithmic transparency and data privacy (e.g., employee surveillance and privacy issues) are noted but not deeply resolved. This leaves a critical area for further attention given evolving legal and institutional regulations across countries and regions [6, 25, 26].

Future research should explore three key directions. First, studies can investigate the effect of contextual contingencies on the functioning of AI-enabled SRHRM systems. For example, how do industry type (e.g., knowledge-intensive firms, health-care organizations, gig platforms), organizational culture, or national institutional frameworks moderate the effectiveness of AI-enabled SRHRM systems? In addition, cross-cultural comparative studies could reveal how relational values shape AI adoption differently across contexts. Second, future research can also investigate the micro-level dynamics. Experimental or diary studies could unpack how employees' daily interactions with AI (e.g., chatbots, algorithmic feedback) alter their relational KSAs over time, including but not limited to unintended consequences like emotional exhaustion or over-reliance on machines. Third, scholars can also examine how AI-enabled SRHRM systems can be further improved by the codesign of scholars and practitioners. As AI evolves (e.g., generative AI for HRM, the creation of AI agents in HRM), research should revisit how emergent technologies like emotion-sensing algorithms or virtual team facilitators complement or complicate relational HRM. By addressing these gaps, scholars can advance both theory and practice toward human-AI symbiosis in the workplace.

7. Conclusion

This chapter explores the transformative intersection of AI and SRHRM to offer a framework that reconciles technological advancements with the human-centric foundations of workplace relationships. At its core, this chapter highlights a critical paradox that needs to be addressed urgently: while AI-driven HRM tools can enhance efficiency and reduce bias, their unchecked adoption risks eroding the trust, collaboration, and social capital that underpin organizational resilience and sustainable competitive advantage. By synthesizing insights from strategic HRM, HRM digitalization, and social capital literature, this chapter advances an AI-enabled SRHRM model that repositions AI not as a replacement for human judgment but as a relational stakeholder. The model's five adaptive strategies, ranging from inclusive relational KSAs to hybrid human-AI practice design, provide a theoretical framework for organizations to benefit from AI's analytical power while ensuring the relational mechanisms essential for innovation, employee well-being, and long-term success of firms.

The chapter's theoretical contribution lies in its integration of fragmented discourses on AI and relational HRM, which challenges the prevailing transactional view of AI as a mere efficiency-improving tool. Instead, it reframes AI as a relational agent that is capable of augmenting (rather than displacing) human connections when designed with transparency, stakeholder cocreation, and ethical accountability. Practically, the model equips HRM professionals and organizational leaders with actionable strategies to navigate AI integration, such as leveraging relational analytics to monitor social capital or embedding explainable AI principles in important HRM decisions.

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Conflict of interest

The authors declare no conflict of interest.

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Section 2

Challenges and Opportunities

Challenges and Opportunities of STEM Education: The Implication for Ethiopia

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Abstract

Globally, there is an increasing concern about STEM education for the socio-economic growth of nations. The developed countries have already benefited from its blessings. In developing countries like Ethiopia, although STEM education is widely acknowledged as a strategy to enhance economic development, many challenges hinder its implementation as intended in policy documents. Using a systematic review approach, this chapter explored the current status, challenges, and opportunities of STEM education, focusing on the global context and its implications for SSA countries vis-à-vis Ethiopia. In Ethiopia, the government has several policy documents supporting the implementation of STEM education. The ten-year transformation plan mentioned rising youth employment, creating 1.36 million new jobs per annum concerning achieving accelerated and sustained economic growth, and has emphasized shifting the economic bases from agriculture-led to industry-led. Lack of qualified teachers, a well-developed curriculum, well-equipped schools, and the deteriorating trend of students joining hard science fields are among the challenges to precede as intended. A large number of trainable human capitals of the country, the world's skills shortage, and the demand for a green economy are opportunities for the government to dwell in STEM education. The chapter recommends the SSA countries like Ethiopia to use the late comer advantage to best benefit from the legacy STEM Education.

Keywords: challenges of STEM education, economic development, interdisciplinary, STEM education, trans-disciplinary

1. Introduction

1.1 Background of the study

Globally, there is an increasing concern about the significance of Science, Technology, Engineering, and Mathematics (STEM) education for the socio-economic growth of nations. It is recognized as a tool that assists sub-Saharan African (SSA) countries to realize the ambition of becoming middle-income countries [1–3].

Regardless of the comparative importance of STEM education to produce a competent workforce and to introduce new and simplified production, working methods, and working cultures, it is very unsatisfactory that students' interest in joining those fields, the disparity in gender, and the performance of those who graduated from those fields is destitute [1, 4, 5]. While it is a promising sign to see many countries nowadays incorporating science, technology, and innovation agendas in their national development policies, the implementation is facing many challenges. Lack of qualified teachers, well-developed curriculum, well-equipped laboratories, and other supportive educational materials are among the challenges to proceed as intended in the policy documents and to facilitate the achievement of national interests [4, 6]. Thus, national concern to produce more science and technology personnel on the one hand and to decrease the number of students who are interested in joining these fields, and hence, their limited competency on the other hand is a concern that needs immediate attention [1, 4]. A labor force that is not equipped with the right skills in STEM education cannot fit the current market demand and will fail to meet the needs of the increasing manufacturing and construction industry [1, 6, 7].

1.2 Statement of the problem

What does STEM education mean? How do the policy documents mention STEM? Is it a curriculum approach, an instructional approach, or a discipline? If it is a discipline what is the modality in Ethiopia? How is the development? How it should be implemented in practice? Are all subjects, that is, physics, chemistry, biology, mathematics, technology, and engineering well addressed in STEM education? What do the T and E in STEM represent at the school level? Which aspects of STEM are technology and engineering? Do teachers at schools have the required orientation and competency to guide gifted and talented students in STEM education? All these and other similar questions are controversial in the literature. Besides, there is no clarity on the overall benefits and challenges of implementing STEM education [8, 9]. Moreover, these questions are not clearly articulated in Ethiopian education or related Science and Technology policy documents.

Without reaching a consensus and achieving clarity on these concepts, the institutionalization and sustainability of the program remain uncertain. Achieving clarity, however, requires research-based evidence and evidence-based decision-making. In other words, there is a need to conduct a study exploring its development, current status, and lessons to be learned from its progress. Therefore, in light of the above argument, this study aims to critically reflect on the current status, challenges, and opportunities of implementing STEM education in SSA countries like Ethiopia.

1.3 Objective of the study

Thus, this study is intended to answer the questions with the help of an exhaustive literature review from the local and global archives. The study aimed to attain the following objectives:

- Critically analyze the literature to identify the way it is defined, approached, and its modality.
- Uncover opportunities and challenges in the implementation of STEM education in SSA taking Ethiopia as a case.

In doing so, the study contributes to understanding the definition of STEM education, the current status, challenges, and opportunities of implementing STEM education. Besides, the study identifies the existing opportunities for educational institutions, teachers, students, researchers, and policymakers. Most of the works of literature on STEM are from the developed countries [10, 11], and there are also several systematics and biometric reviews on STEM education [10–14] but all of them are concerned about the status, trends, and challenges in their context as all the authors of those reviews are not from this study area context. Hence, preceding empirical studies have limited contributions to a better understanding of STEM education for developing countries like Ethiopia. Besides, no studies have been conducted in Ethiopia about STEM education. Thus, this study has added value to enrich the literature on STEM education and highlights the implication of the literature to SSA country's context. To attain the first objective, documents were systematically collected from databases and specific journals. To attain the second objective, both academic and gray literature, policy documents, reports, and official Web sites were used.

2. Research methodology

This study is a systematic review conducted based on the PRISMA guideline, as suggested by Moher et al. [15]. Accordingly, this research methodology section describes how the review was planned, including the procedures used to determine potential document sources, the time frame, and searching parameters. It also details the actual document retrieval from those identified sources, followed by screening criteria, and finally, how the review was conducted and how the data were analyzed.

2.1 Planning the review

The reviewed documents were systematically collected from databases and specific journals using a keyword search followed by an iterative process. The document search was largely influenced by previous systematic reviews [10, 11]. Considering previous reviews, the diverse perspectives, and the complexity and ambiguity of determining the scope of a literature search on STEM education, [10] derived location criteria and time limit. Accordingly, they identified 36 journals as a potential publisher or sources of documents on STEM education. They identified a total of 798 articles published in those 36 journals which are labeled as STEM education, discipline-based education, and general education journals from 2000 to 2018. Their review revealed the rapid rise in publications, from fewer than 10 per year before 2010 to more than 100 per year since 2016 and consistently rising. Besides, Li et al. [10] argued that many journals that publish STEM education articles are not included in the most known databases such as the Web of Science (WoS) and Scopus, hence suggesting using specific journals rather than using databases. Generally, the article mentioned that the vibrant nature of the field, the lack of well-known journals or publishers straight forward like that of the traditional disciplinary fields, and the diverse perspective about the field among educators make it difficult to locate, distinguish, and categorize publications as STEM education and hence challenge to conduct a review.

On the contrary, to determine the research progress on STEM education using a bibliometric analysis, Cai et al. [11] used WoS database. The data collection

ranges from January 1, 1985, to December 31, 2021, bringing 1910 documents together that mainly published from 2010 to 2021, whereas the number of publications before 2010 is insignificant. The document, as part of the analysis, identified the top 10 journals indexed in Web of Science having the most articles identified. Besides, Mintii [13] used both Scopus and WoS databases to search for a bibliometric analysis of a review entitled STEM Education and Personnel Training. Moreover, Sungur-Gül et al. [12] used scientific journals index in Social Science Citation Index (SSCI) and Science Citation Index Expanded (SCIE) for a review aimed at investigating the trends, main advantages, and challenges of STEM education in k-12, whereas Galic and Kocadere [14] used WoS database to identify the current trends and challenges of STEM education using bibliometric analysis followed by a narrative review.

In a systematic literature review and synthesis of journal articles for an Assessment of Transversal Skills in STEM (ATS STEM) in eight European Union Countries from 2010 to 2019, McLoughlin et al. [16] used the Scopus database and identified 79 articles for final analysis. According to this document, Scopus is the most comprehensive repository for studies within the STEM discipline (p. 12). The document, by referring to a recent study on comparison of the two databases, wants on saying while Scopus has a larger number of journals in the range from 1996 onwards; WoS has strong coverage, which goes back to 1990. The study also mentioned that the STEM literature from 2001 to 2010 covers only 5.7% of the total literature from 2001 to 2019.

Thus, from these reviews, it is evident that 2010 is a preferred starting point for the literature search for the current review. Besides, the potential journals identified by those reviews are available on SSCI and SCIE that are parts of WoS database. Accordingly, we performed a literature search on SSCI, SCIE, and ScienceDirect databases containing the key term “STEM education” in combination with status, challenges, advantages, disadvantages, and opportunities in title, abstract, or key terms. The search parameters include document type: article, review article, book, book chapter, and conference paper, language: English, category: Education research, education scientific discipline, and multidisciplinary sciences, year: 2010–2023, Permission: open access.

2.2 Document retrieval

The data retrieval from the identified databases was conducted on October 20–26, 2023, producing 763 documents after removing duplications. The search terms “STEM education status,” “STEM education challenges,” “STEM education advantage,” “STEM education disadvantage,” and “STEM education opportunities” were used. The term “STEM” alone was not used as it was confused with the most common term “stem” in biology. For instance, while a single search in Google Scholar using “STEM” produced 5,670,000 documents in 0.06 seconds, when it integrated with education it reduced the result to 4,500,000 in 0.07 seconds.

2.3 Inclusion/ exclusion criteria

The research team members evaluated each document to determine the extent it qualify for further consideration by looking at its title, key terms, and abstract. To extract the studies for final analysis the following criteria were used: Empirical

studies, review articles, books, book chapters, or conference papers that include the search terms “STEM education” in either title, keyword, or abstract; studies that are supposed to provide sufficient information about STEM education, that is, current status, opportunities, advantages, disadvantages, or challenges done in any education level K-16, and written in English language and studies that are freely available or have open access for full document retrieval. Documents such as theses or dissertations, studies lacking sufficient or relevant information aligned with the study objective, and article for which the full text could not be obtained, whether through institutional library access or direct request to the authors via platforms such as ResearchGate, were excluded from the review. Accordingly, 47 studies were selected.

By reviewing the reference list of these articles (especially those review articles) and looking at national and international databases, the search was extended. The iterative searching process produced not only relevant articles but also some important reports and Web sites that directly reflect the facts on the ground in the study area context. Hence, international organization reports, working papers, government policy documents, and official Web sites were used. The country-specific policy documents, official information, and communications were also incorporated from official Web sites and hard-copy documents. Local documents were collected through the researchers’ exposure to the sector. This search ended by producing 26 documents of which five of them are already included in the 47 documents identified above. Hence, the search ended in producing a total of 68 documents. **Figure 1** summarizes the screening process of the documents.

The collected documents were managed using Mendeley Desktop reference manager software. The documents used to attain the objectives are summarized in **Table 1**.

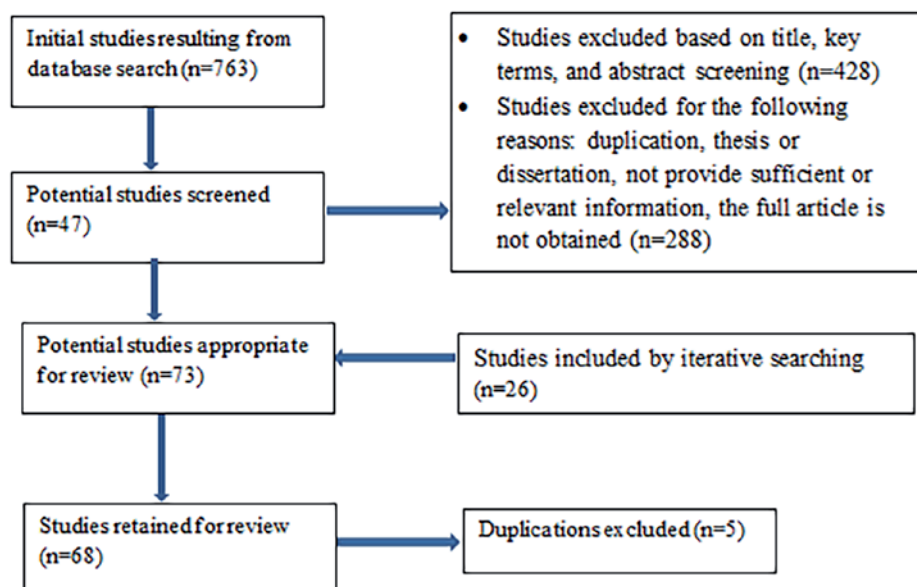


Figure 1.
 Flowchart of the screening process.

Type of documents	Number of documents		
	From databases	From iterative search	Total
International report & working Papers	4	5	9
Book	4	0	4
Book chapter	3	1	4
Article	26	2	28
Review article	5	4	9
Conference proceeding	1	1	2
National policy documents	1	4	5
Website	3	4	7
	47	21	68

Table 1.
Literature search result.

2.4 Conducting the review

The studies selected for the final analysis were read over and over again by rotating through the review team using highlights on the pdf documents using different colors for each reviewer. The review team discussed the extracted quotations. Further discussions were conducted to minimize disagreements. Finally, a table of data extraction was prepared with a heading row containing: document type (empirical, review, book, book chapter, report, conference paper, policy document, and Web site), year of publication, educational level (elementary, secondary, upper secondary, and not specified), country, focus area (definition, trend/status, challenge, and opportunity/advantage), and listed recommendations. Thus, a discursive content analysis [17] was used as a core tool to analyze the textual data strings. This approach facilitated the data analysis by exploring meaning beyond words and achieving the study's intended objectives.

3. Result and discussion

3.1 STEM and STEM education definition

While the term “STEM education” remains contested and lacks a unified definition and scope [10, 18–22], the literature consistently affirms a consensus on the meaning of the acronym “STEM” as referring to Science, Technology, Engineering, and Mathematics (For instance, [22, 23]. Hence, STEM education is a teaching-learning approach in which concepts from the areas of science, technology, engineering, and mathematics are integrated [24, 25]. The engineering and technology practices can instead be blended into existing mathematics and science lessons in ways that engage students and help them master twenty-first-century competency hence contributing to the economic development of countries [20, 26].

According to the document by [27], *STEM is a curriculum based on the idea of educating students in four specific disciplines—science, technology, engineering, and mathematics. When taught in school, STEM education uses an interdisciplinary, hands-on*

approach that relates to real-world applications. As per Ref. ([28], p. 159) STEM is a “curriculum of research-based pedagogy.” Hence, STEM students perform better than their counterparts in traditional pedagogy in terms of building confidence and creativity, earning higher income, and applying innovative approaches. In the traditional approach, also known as the “fragmented approach,” concepts in each subject of the STEM disciplines are learned discretely with firm disciplinary boundaries. In STEM, the approach is “holistic and systemic” where concepts from different subjects are linked and thought to solve a real-world problem. Accordingly, the approach is “trans-disciplinary” [29, 30]. Refs. [25, 31] characterize STEM education as a meta-discipline, that is, a discipline created by integrating concepts from the constituting disciplines into a new whole and addressed as one-dynamic fluid subject matter. According to Lantz [32], this interdisciplinary nature of STEM provides students with a comprehensive picture of the world or a problem rather than fragmented and isolated pieces.

In terms of describing STEM education as an integrated approach while Sanders [33] expressed it as a teaching–learning approach that integrates STEM subjects with and/or without STEM subjects/other school subjects like art, Moore and Smith [34] focus on the integration of the four STEM subjects, that is, science, technology, engineering, and mathematics “into one class, unit, or lesson that is based on a connection between the subjects and the real-world problem.” Hence, the approach requires thinking differently in terms of teachers’ development, curriculum development, instruction, and assessment ([35], p. 246).

Based on a review of 17 articles, Bybee ([19], p. 2) summarized the STEM education definition into four: STEM as a discipline, STEM as instruction, STEM as a field, and STEM as a career. STEM as a discipline involves teaching concepts from the four STEM subjects as a holistic and one depending on the other, rather than teaching them separately. This description agrees with what Marken Group [27] and English [29] termed as trans-disciplinary. This type of integration enforces teachers to teach any of the subjects constituting STEM [2]. On the other hand, those who defined STEM as an instruction consider the natural connection among concepts in those disciplines to enhance student’s understanding and make sense of the learning process through their active participation and involvement in a different approach than the traditional methods. In doing so, it is believed that the approach enhances not only students’ performance and involvement but also their attitude and hence paves the foundation to choose careers in STEM fields [36].

The next definition, STEM as a field of study, focuses on countries’ strategies to enhance their citizens’ logical thinking, critical reasoning, and problem-solving, as a result increasing those who are confident and successful to join STEM fields of study, which in turn increases the individuals in particular and the country in general computation in the job market [8, 26]. This definition is more feasible at post-secondary and tertiary education levels because this is the stage where students choose their field of study as a STEM or non-STEM stream [20]. Thus, the attention and incentives provided at this stage to attract more participants determine the country’s intention to benefit from the STEM blessing. Finally, STEM as a career focuses on learners’ intention to pursue STEM-related or STEM subfields careers independently or without exposure to the other. This definition is more feasible at a career level than at an education level [20].

As suggested by Breiner et al. [8], the definitions of STEM education vary considerably based on the level of education, that is, at the primary level the integration of STEM education is not clear, and at the secondary school level to some extent the

integration of the disciplines is feasible [37]. At upper secondary, by default, the fields are either STEM or non-STEM. While for Margot and Kettler [38], its interdisciplinary nature placed STEM education both a curricular and a pedagogical approach, for Ref. ([9], p. 1) “It is a pedagogy and philosophy to embed the new generation with the 4Cs framework, i.e., communication, collaboration, creativity, and critical thinking.”

3.2 The dispute regarding STEM integration

Although it is widely accepted that STEM is an integrated curriculum and instructional approach of the four disciplines, there are variations in the nature and scope of integration among the disciplines and the role of each discipline in the integrated curriculum [39]. The different integration approaches given by Vasquez et al. [40] are comprehensive and are also adopted by Goos et al. [39]. Based on the integration approach, there are many questions raised by researchers and teachers such as: Is it practical always to develop a problem that constitutes concepts from all the four disciplines? What is the role of each discipline in the integrated curriculum like mathematics? “What do the T and E in STEM represent at the school level?” are the most commonly asked and are a stumbling block to reaching a consensus, especially by school teachers or parents, and hence hesitate about its feasibility [39–43].

Technology for some is the use of computers but this is in a very narrow sense as technology is more than this and computers are just one such tool [44]. According to Lantz ([32], p. 5) the E (the engineering component) is addressed by “the process and design of solutions, instead of the solutions themselves” so that students explore science and mathematics to enhance their understanding and critical thinking and problem-solving skills. Hence, “engineering design is a pedagogical strategy that promotes learning across disciplines” ([32], p. 5). On the other hand, the T (the technology component) facilitates a better understanding of concepts in the other three components with the help of computers and applications, simulations, games, animations, visualizations, graphics, and drawing tools [32]. Hence, “while science and mathematics are the core subjects of STEM Education, technology, and engineering are a tool for STEM Education” ([14], p. 103). A long history in short ([17], p. 39) identified seven characteristics of integrated STEM education: core STEM competencies; problem-solving design and approach; disciplinary and interdisciplinary knowledge; engineering design and practices; appropriate use and application of technology; use of real-world contexts; and appropriate pedagogical practices.

3.3 STEM development

The history of STEM is dominated by the literature from the USA since the first time the acronym was introduced in the 1990s as SMET later in 2001 converted to STEM [6, 16, 20, 45–47]. Of course, the attention to science, and mathematics and hence on innovations goes back to the history of the computation between the USA and the USSR, in the era called “The Sputnik Era” [27, 44]. According to Marken Group [27]:

The spark that put the U.S. on the path to technology and innovation was the launch of the Russian satellite, Sputnik, into space. The year was 1957, and Americans put their competitive spirit into motion.

Since then more attention has been given to science and mathematics courses at different levels of the education system. Besides, important education councils have

been established, supporting political documents have been designed, and engineering and technology institutions and industries have been established [29].

The literature on STEM education has highly increased since 2010, [10, 20, 21] from which lessons can be learned but dominated by the experience from the developed countries context especially the USA which accounts for around 75% of the total publications [10]. In SSA, let alone to compare with the rest of the world, within the SSA itself the literature in STEM is considerably less than in non-STEM fields [7]. Based on a Scopus database search from 2003 to 2012 the same document mentioned that the research output in STEM in the region declined by 0.2% annually. In contrast, the document mentioned the significance of STEM education for the economic transformation of the region [7].

Nowadays, investment in STEM education is the new sector of computation for developed and industrialized countries [1, 20, 26]. While the East Asian countries have already performed better and are leading the world in terms of students' scores in STEM subjects and hence have benefitted from its blessings, that is, rewarding employment opportunities and national economic development, the Western countries including the USA and the UK are still straggling and investing heavily not to be bitten by the East Asian Tigers [1, 22, 23]. **Figure 2** describes the percentage of STEM graduates as compared to the total tertiary education graduates in the selected countries in 2022 [48]. While China is not included in the figure due to lack of comparability in data, it has the highest enrolment and largest number of STEM graduates in the world [49]. Besides, STEM has a short history in China as compared to the USA; China is also leading the world in terms of research and publication surpassing the USA for the first time in 2021 and has an increasing trend [49].

SSA countries like Ethiopia have to recognize the key role STEM education plays in creating a competent, motivated, and skillful workforce for the labor market and hence for the national economic development and achieving the SDGs. According to Ref. [50], STEM is the tool to close the gap between SSA and the other parts of the world economy. Some evolvments have been made but not enough as compared to the backlog [3, 7], the seep of the job market is changing, and also, the half-life of knowledge in the technology fields is short [1, 21].



Figure 2.
 Countries with the highest percentage of STEM graduates from their tertiary education graduates.

3.4 The importance of STEM

Whatever the approach is, “the ultimate goal of STEM education is to provide a high-quality STEM workforce” [40, 50, 51]. In the process of achieving this goal, it has been recognized in terms of enhancing students’ interest and achievement in science, that is, biology, chemistry, and physics subjects more than the traditional approach [10, 22] and hence has both educational and workforce importance [29, 49, 51]. In particular, STEM education allows students to solve real-world problems and authentically create and build their ideas, promoting depth of understanding as well as adaptability to skills needed to succeed in the changing world. In particular, STEM education:

- boosts students’ interest, understanding, and achievement [13, 39, 52],
- allows students to make sense of the concepts that they are learning, relate those concepts to real-world problems, and use their understanding to fast-track scientific innovations [9, 27, 29, 53, 54],
- makes students problem solvers, innovators, inventors, self-reliant, logical thinkers, and technologically literate [31, 53],
- addresses contemporary issues such as innovation, entrepreneurship, self-employment, reducing unemployment, and local development needs [3, 24] and hence increases global competitiveness [37, 55],
- brings into line the demand and supply of skills in the job market [2, 21, 29, 45], in general safeguards growth in the economy [3, 20],
- increases job opportunities, reduces social costs, and prevents brain drain [56], contributes to the achievement of the SDG4 [6, 57], is a new field of collaboration [58], and is a strong driver of competitive national economies [55].

Besides, the twenty-first-century job market demanded a new set of skills (critical thinking, problem-solving, collaboration, and self-directed learning), and these skills acquired through STEM education [2, 3, 9, 19, 20, 37, 39].

3.5 Challenges of STEM education

While STEM education gets the attention of policymakers, educators, and researchers from many countries, its implementation has many challenges in terms of forming an integrated curriculum, producing qualified teachers, lack of materials for practical work, and designing appropriate assessment tools. Besides, the decline in students’ interest in STEM disciplines at all levels and inequality in STEM, including gender disparity [13], are among the challenges that hinder its implementation. The following are specific examples from the different countries that hinder or lead to unsuccessful implementation of STEM education:

- China: challenges in subject integration, teacher development, and lack of teaching innovation, and effective evaluation.
- Ghana: lack of appropriate teaching-learning materials and suitable infrastructure, limited certified STEM teachers and inadequate professional

development opportunities, lack of standards and document preparation frameworks, limited access to technology, and shortage of time for teaching STEM-related subjects [43],

- Pakistan: insufficient teacher training, access to labs and related qualified staff, lack of understanding of the significance of STEM education, the problem of curriculum integration [57, 59],
- Turkey: the lack of clear definition and understanding of what STEM is among practitioners, its status quo in the curriculum and how it will be interpreted in the classroom, and lack of teacher's training framework [13],
- Vietnam: inadequacy in teacher preparation, the lack of a curriculum framework and assessment guidelines, teaching materials, lack of sufficient technical, time, and space resources, and the lack of teachers' awareness about STEM education and its educational goals ([60], p. 5),
- Zambia: lack of appropriate STEM curriculum, improper teacher training, lack of teaching-learning materials and limited access to internet connectivity for research, and poorly supplied laboratories and technicians [61],

It is also found that not only scarce discipline knowledge, skill, and attitude of teachers but also a lack of pedagogical knowledge and absence of continuous professional development programs to fill existing gaps among the challenges in STEM education [29, 62, 63]. In general in a review to examine trends and challenges of STEM education in the last five years (2018–2022), Galic and Kocadere [14] categorized the challenges collected from 14 articles identified for the review as follows:

- curriculum challenges: include the disagreement between STEM education and existing curriculum requirements, lack of materials suitable for STEM lessons, assessment methodologies, and tools suitable for STEM projects,
- administrative challenges: lack of linkage between universities and schools, busy schedules of academicians, and lack of support to teachers,
- cultural challenges: language barriers, gender inequality, lack of interaction between science and culture, and
- professional development challenges: lack of knowledge, skill and instructional approach for the new lessons, and teachers' lack of comfort with their changing role.

Moreover, lack of clear understanding and consensus on what STEM education and its approach (for instance, disciplinary [20], interdisciplinary [6, 38, 39, 58], or trans-disciplinary [29, 30, 32, 64], multidisciplinary [65], meta-disciplinary [52, 55]) and hence its approach (for instance, a curriculum [52], an instructional approach [55], a curriculum, and instructional/pedagogical approach [6, 66]) are among the challenges that hinder its effective implementation. Furthermore, key challenges frequently mentioned include the compromise of subject integrity for economic gains, the lack of equitable representation across disciplines [67], and the absence of

appropriate assessment frameworks for interdisciplinary learning [42]. For instance, mathematics, often highlighted as the “M” in STEM, is increasingly viewed merely as a tool to support other disciplines. This instrumental approach undermines its broader educational purpose such as fostering critical thinking and preparing learners to become informed, democratic citizens [39].

3.6 Current status of STEM education in Ethiopia

With the country’s regime change in 1991, a new education policy was implemented, and with it came the implicit introduction of the concept of STEM. This included improving science and technology education. The first GEQIP [68] and the 2009 Curriculum Framework [69], both specifically targeted raising standards in science and mathematics education. Two methods of introducing science were provided by the curriculum framework, that is, integrated for grades 5 and 6 and separate sciences subject beginning in grade 7 and onward. Aspects of the three distinct sciences: Biology, chemistry, and physics are combined in integrated science, as the name implies. This is usually done with themes from applied science, like health and agriculture. Besides, the curriculum framework introduced new subjects at the secondary school level including technical drawing and ICT (which incorporate concepts from computer science, information systems, and information technology).

The first Growth and Transformation Plane ([70], p. 52) was more explicit in terms of signifying what to do well on STEM education: *“Fully implementing the Math and Science strategy; raising student awareness and motivation for improved learning in math and science and achieving better results in these subjects.”* Besides, the document proposed to establish science and technology institutions that will focus on serving gifted students and producing competent scientists and engineers.

The milestone of the emphasis on STEM in Ethiopia was the higher education institutions (HEI’s) 70:30 intake ratios intended in 2010 and planned for 10 years. According to this policy, the intake ratio of HEI’s will be 70% for Science and Technology and the remaining 30% for Social Sciences and Humanities as stated in the IV ESDP [71]. The first National Science, Technology and Innovation Policy was also introduced in the same year [72]. The policy document accepted the 70:30 strategy as a key to human resource development of the sector and went on saying “Sustain the 70:30 university intake ratios in favour of science & Technology for the coming 10 years” (p. 5).

The country has acknowledged that its growth depends very much on the expansion of science and technology personnel and thus highly investing in STEM education [73]. To strengthen STEM education, the government has formulated policies and strategies such as a national science, technology, and innovation policy [72], a national program for strengthening mathematics and science education (SMASEE) [74], and a strategic policy for national science, technology, and mathematics education (STME) [75]. The current education policy mentioned that attention should be given not only to the subjects (science, mathematics, technology, engineering, and art) but also to teachers’ empowerment, establishing science and technology laboratories and workshops to support the nation’s job creation and economic development ([75], p. 16). With all these efforts, the country has been recognized as “high-level growth but low-level of technological learning” and “a mismatch between ‘policy formulation’ and ‘policy implementation’ ([76], p. xiv).” Thus, the problem is not a lack of policy document, road map, or framework but rather the implementation gap due to capacity limitations, misallocation of resources, or lack of awareness of the significance of the documents.

At this time, there are several centers of excellence [77, 78] and two universities specializing in STEM fields called science and technology universities, that is, Addis Ababa Science and Technology University [79], and Adama Science and Technology University [80]. Other universities in the country also have both undergraduate and postgraduate programs in almost all the seven fields of specialization identified by the International Standard Classification of Education (ISCED) but these two universities are special from admission to graduation in their attention to the STEM fields. STEMpower and STEM Synergy are NGOs exhaustively working in STEM education in Ethiopia [78, 81]. The STEM centers built by these non-profit organizations are doing well in terms of providing chances for those who have talent but have no chance for such facilities. **Figure 3** describes Grade 7 students working at one of the STEM centers (Photo from STEM Synergy Ethiopia website).

While some universities in the country have established their own STEM centers such as Kotobe Education University, Hawasa University, and Bahir Dare University to assist gifted and talented students' from the surrounding schools, some others have different packages to assist implementation of STEM education. For instance, establish STEM incubation centers, conduct STEM outreach services and science fairs, and conduct summer STEM programs at universities for talented students selected from catchment area schools.

An educational road map [5] that intended to make a reform on the education sector following the national vision and national development goals and hence to make alignment of the country's goal with the SDG (SDG, 2030) has been recently launched. As part of the road map development, an assessment made on challenges of the education system revealed that students' learning outcomes are very low and have a deteriorating trend, graduates lack the necessary competence and skills to join the world of work upon completion of grade 12, most of them are job seekers and not job creators, teachers lack the energy to motivate students to learn, teachers' turnover



Figure 3.
Grade 7 students working at one of the STEM centers.

is high, students comment the teaching approach as in part boring, teaching-learning is not practice-oriented, and the schools are below standard [5]. The data from the Ministry of Education also show that the disparity between urban and rural areas, and male and female enrolment is very wide at both junior schools and high schools [73]. Thus, the education system is still not ready to equip graduates with twenty-first-century skills. Besides, Salmi et al. [77] emphasized short supply of qualified science and technology academic staff limited to advanced benefits of higher education in Ethiopia.

The last two years' national examination assessment results disclosed that the quality of education is diminishing from time to time [82]. This is mainly due to the inability to access and use technologies, inadequacy of infrastructure, poor educational leadership, skill gap of the teachers, absence and insufficient library services, and lack of a supportive teaching system [83]. The gap is more visible in STEM education as it requires both hands-on and minds-on preparation and practice [5, 78].

In general, the challenges that are observed in other parts of the world also create resistance to the expected benefits of the sector in Ethiopia. In particular,

- There are no teachers trained for this purpose, and hence, there is a lack of manpower to create inter or trans-disciplinary-learning objectives and to design learning or assessment tasks to link concepts and skills through a real-world context ([37], p. 1),
- Teachers' quality and attitudes, knowledge, and skill are already challenging for a single subject, and hence, it would be even more difficult to develop teachers that do well on interdisciplinary or trans-disciplinary levels ([33], p. 1).
- Lack of necessary resources and lab equipment [5, 83]: currently, almost all full-flagged STEM centers are those built by STEMpower [78].

With all these challenges, in the words of Ismail ([51], p. 8) "an investment in STEM is needed for a transformative shift in Africa" to realize that STEM education is beyond a new name for the traditional approach to teaching natural science and mathematics subjects or it is beyond using laboratory to teach the science subjects nor using computer to assist teaching mathematics at secondary schools. Misconceptions such as technology mean computers for schools, teachers or students, technology, and engineering fit only to post-secondary school level should have to be avoided through continuous awareness creation and professional development programs.

In particular, lack of clear understanding of STEM education, that is, what is the modality (disciplinary, interdisciplinary, or multidisciplinary), no teacher training modality for this purpose, lack of teachers' quality and attitude, knowledge, and skill, lack of necessary resources, lack of well-developed curriculum, lack of well-equipped school facilities, and deteriorating trend of students to join hard science fields are among the challenges to proceed as intended in the policy documents in Ethiopia.

3.7 Opportunities to enhance STEM education in Ethiopia

A report that investigated skills shortage in the world [46] indicated the global community's need for a green economy. To achieve a green economy, scientist needs to engage in serious research and brings forward knowledge on how we use energy that is recyclable and do not pollute the ecosystems. Therefore, the current status of nature

demands more scientific skills in water conservation, energy efficiency, and strategies to combat pollution and its impact. International studies such as TIMSS and SACMEQ clearly show that in many countries students struggle to reach the international mean in their mathematics performance. Besides, the literature is full of evidence about the importance of skills in STEM in the next decades. For instance, the US Bureau of Labor Statistics projected in the year 2019–2029, and STEM-related job opportunities grow two times (8%) faster than the total for all other job opportunities (3.7%) [47]. In particular, in Ethiopia, the construction of different industrial parks, increasing power generation and supply capacity, and building of a climate-resilient green economy on one hand and increasing urbanization and huge infrastructure deficits, on the other hand, catalyze the demand for engineering, technology, and applied science solutions to areas such as water and sanitation, power generation and supply, environmental management, transportation, and communications [77]. Improved performance in STEM education is one of the means to realize countries full potential in a competitive global market increasingly shaped by the use of new technologies. In SSA, the importance of developing skills and knowledge in STEM subjects to promote and sustain growth is now widely acknowledged [7].

Ethiopia is in an economic transformation: from agricultural to industrial. Secondary schools are the section where developing countries like Ethiopia produce most of their lower- and middle-level manpower. Thus, national concern to produce more science and technology personnel on the one hand and the decreased number of students who are interested in joining this field and hence their limited competency, on the other hand, are a concern that needs immediate attention. The country's 10-year transformation plan mentioned reducing youth unemployment by creating 1.36 million new jobs per annum for achieving accelerated and sustained economic growth. Thus, the large number of trainable human capital of the country, the skills shortage in the job market, and the demand for a green economy are opportunities for the country that engine to do well in STEM education and benefit from its blessings.

Thus, to get the best benefits of STEM education, areas of intervention include tutorials and support to students, skill training for teachers and principals, upgrading opportunities for teachers, and material support (computers, laboratory equipment, and other technologies: techno-ware, hardware, software) that need immediate attention. The current best experiences that have been seen in STEM centers, the attention given by universities to support secondary schools and students in their catchment areas, and involvement of organizations like STEM Synergy are opportunities to do well in the future. Projects may be designed and carried out to attain the following objectives:

- To provide training and upgrading opportunities for secondary school teachers,
- To enhance the performance of staff and managers in the STEM sector,
- To produce more research in the area of STEM education,
- To pave knowledge-based decisions on STEM issues,
- To establish communal science resource centers,
- To provide opportunities for gifted and talented students in STEM,
- To provide training on ICT-based pedagogy and database support systems.

The projects are worthwhile from the perspective that “the socioeconomic status (SES) of the school is a significantly more important factor in determining outcomes than the SES of the student and their family [84].” Besides, prepare national STEM standards and frameworks including the definitions and integrated approaches, prepare STEM teachers certification framework and training, prepare STEM education curriculum, establish additional STEM incubation centers, capacitate secondary school laboratories and libraries, especially in chemistry, physics, biology, ICT, mathematics, and technical drawing, develop ICT-based pedagogical and database support systems, and introduce a strong teacher management system are intervention areas that need immediate attention. After all, the cumulative effect will be a better qualified and competent workforce in the field of STEM.

4. Conclusion

Current jobs are disappearing due to automation, and new jobs are emerging every day as a result of technological advances. The continual advances in technology do not change only the nature of the job market but also change the way students learn, connect, and interact every day. Skills developed through STEM education provide students with the foundation to succeed at school and beyond. Improved performance in STEM education is one of the means to realize countries’ full potential in a competitive global market increasingly shaped by the use of new technologies. In Ethiopia, the importance of developing skills and knowledge in STEM subjects to promote and sustain growth is now widely acknowledged. Steps have been taken in recent years to increase the number of students and researchers involved in STEM-related activities and to raise the quality of work in this field. This is essential if countries are to achieve the SDGs and close the gap between SSA and the rest of the world in these fields.

STEM education in Ethiopia, except for the practice in some STEM centers, is still focused on improving science (biology, chemistry, and physics) and mathematics as isolated disciplines. Such a fragmented or disciplinary approach is at least two and half decades behind the current development of the field since the other world is talking at an interdisciplinary or trans-disciplinary level. On the other hand, Ethiopia is in an economic transformation: from agricultural to industrial. Thus, national concern to produce more science and technology personnel on the one hand and the decreased number of students who are interested in joining this field and hence their limited competency, on the other hand, are a concern that needs immediate attention. The country’s 10-year transformation plan mentioned reducing youth unemployment by creating 1.36 million new jobs per annum for achieving accelerated and sustained economic growth. Lack of clear understanding of STEM education, that is, what is the modality in Ethiopia (disciplinary, interdisciplinary, or multidisciplinary), no teachers training modality for this purpose, lack of teachers’ quality and attitude, knowledge and skill, lack of necessary resources, lack of well-developed curriculum, lack of well-equipped school facilities, and deteriorating trend of students to join hard science fields are among the challenges to proceed as intended in the policy documents. Besides, the large number of trainable human capital of the country, the skills shortage in the job market, and the demand for a green economy are opportunities for the country that engine to do well in STEM education and benefit from its blessings. In conclusion, the controversy surrounding STEM education is about a number of fundamental issues, such as:

4.1 Definition and scope of STEM education

STEM is an acronym for Science, Technology, Engineering, and Mathematics. While at school level, some claim that STEM education is an instructional approach integrating these four subjects, and others characterize it a curriculum approach. But both admit that STEM at school level uses an interdisciplinary, hands-on approach to foster critical thinking, problem-solving, creativity, and innovation that are relevant to real-world applications. It is both hands-on and minds-on nature assist learners make sense of what they are learning and hence leads to better performance and engagement in the learning process as compared to the traditional approach. At post-secondary level STEM is a field of study, concerns with countries' intentions to enhance their people's logical minds, critical thinking, and problem-solving in exchange boosting those who are successful and confident to study STEM courses of study, which in turn enhances the individuals in particular and the country at large computation in the job market [8, 27].

4.2 Interdisciplinary vs. disciplinary approach

One of the major arguments in STEM education is the scope of integration, that is, whether or not to teach STEM disciplines as usual with occasional interdisciplinary connections (and hence instructional approach) or completely integrated into problem-based approaches (that avoid the current disciplinary demarcation and hence make STEM a curriculum approach). The answer to this argument is related to the issues that nations face at different level of its implementation. Hence, it is advisable that one should start from the usual interdisciplinary approach and then gradually move to full-fledged interdisciplinary approach. In doing so, whereas science and mathematics are the core subjects of STEM Education, technology and engineering are pedagogical tools of enhancing problem solving involving the core sciences ([14], p. 103). Besides, all the key STEM subjects, that is, biology, chemistry, physics, and mathematics are included under STEM education. But they are taught differently than in the traditional way. Instead of teaching them separately, STEM education integrates them to address real-world issues and infuse the habit of applying knowledge from different fields. For instance, biology and chemistry can be applied together in environmental and health science projects, physics and mathematics often appear together in robotics, mechanics, and engineering design projects, whereas all four can appear together in such fields as energy projects. Technology and engineering at school level are not separate subjects but are integrated into science and mathematics classes so that students can learn to apply knowledge. Practically,

4.3 Technology in STEM

Digital literacy—teaching how to use technological tools such as computers, smartphones, tablets, and the Internet, kids coding and programming—introducing kids to basic programming languages such as Scratch at early age, educational software and simulations—virtual labs, design software, and online science experiments and specific application software like GeoGebra in mathematics, and last but not least is use of technological tools—learning through 3D printing, drones, or robotics kits.

4.4 Engineering in STEM

Design thinking and innovation-encouraging students to design solutions for real-world problems (e.g., designing water filters, bridges, or energy-efficient homes), simple machines and structures—introducing students to basic engineering concepts using scientific tools appropriate to their development levels or using locally available materials, robotics and automation—building simple robots using simple or complex kits that fit to their level of intelligence and interest, and finally, hands-on building projects—engaging students in model-making, electrical circuits, and mechanical systems, using commercial or locally available resources.

4.5 Benefit of STEM education

At school level, the approach enhances not only students' performance and involvement but also their attitude, building confidence, and creativity and hence paves the foundation to choose careers in STEM fields [36]. At the higher education level, applying innovative approaches can lead to better academic outcomes and potentially higher income.

4.6 Challenges of STEM education

While there is a progress made, different challenges impede the successful implementation of STEM education in the region:

- Limited resources: Schools do not have laboratories, computers, and teaching materials.
- Teacher shortages and training gaps: Lack of sufficient qualified STEM teachers.
- Infrastructure shortfalls: Inadequate electricity and Internet access in rural areas.
- Curriculum rigidities: Traditional education systems focusing on memorization rather than critical thinking.

Moreover, the approach requires differently thinking about teachers' development, curriculum planning, teaching, and evaluation ([36], p. 246). It is a practical always to design an issue that synthesize ideas across all the four disciplines. It, however, created issues around the competence of instructors. Besides, extensive resources are required, and this quest for equity and access, that is, STEM education is typically not equally accessible for students from poorer backgrounds, and therefore leading to disparities. Furthermore, there also exists some hesitation regarding the effectiveness of STEM programs, that is, whether STEM programs actually improve student learning and career readiness or if they are more essentially just fashionable education programs without sufficient evidence of long-term effectiveness.

4.7 Opportunities of STEM education

Despite the discrepancies, there are a number of opportunities to advance STEM education:

- Increased digital learning: Wider access to affordable smartphones and Internet coverage provides a platform for online STEM education.

- Government and private sector investment: Increased interest from industries in developing a skilled workforce, the motion “skills rather than degrees.”
- International collaboration: Partnerships with global institutions to enhance STEM resources and training.
- Youth engagement: Greater passion among the youth for technology, innovation, and entrepreneurship.
- Policy reforms: Governments re-writing education policies in order to include more STEM in national curricula.

STEM education holds great potential to transform Sub-Saharan Africa by equipping students with required twenty-first-century skills, while there are issues, strategic investments, policy reforms, and innovative pedagogies can unleash opportunities for economic growth, technological advancement, and sustainable development in the region. The quest for technological and scientific skills that has been seen to be increasingly gaining speed among job hunters has encouraged STEM in sub-Saharan Africa over the last decade. Thus, governments and NGOs have introduced policies, whereas private institutions do so through individual initiatives. Additionally, non-governmental organizations like STEM Synergy have emerged and doing well. STEM education is being implemented in various ways across sub-Saharan Africa:

- Establishment of STEM-focused schools and innovation hubs.
- Introduction of coding, robotics, and engineering projects in schools
- Encouragement of girls’ participation in STEM with specially formulated programs.
- Partnerships with global tech companies for mentorship and resource support.
- Organizing local STEM competitions, science fairs, and STEM campus.

One of the limitations of this study arises from the complexity and ambiguity of determining the scope of a literature search on STEM education, as many journals that publish STEM education articles are not included in the most well-known databases, such as the Web of Science (WoS) and Scopus [10]. Besides, only open-access journals were included, whereas studies in which the full article could not be obtained by any means available to the authors, such as through an institutional library or by requesting the full article from the author *via* ResearchGate, were excluded. Thus, when these parameters are expanded, additional results may be obtained.

Further research to synthesize empirical evidence from similar contexts may save from missing the target like that observed in Zambia [61]. Sound evidence is required to support the ambitious goals outlined in policy documents or the success stories obtained from succeeded countries. The questions: Does it contribute to increasing students’ interest, engagement, performance, and critical thinking, does it not create extra cognitive load or anxiety on teachers, does it align with intelligence, that is, does it have theoretical bases to implement the integrated approach, and does it really produce intended workforce needs further research evidence.

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The Impact of Employee Engagement on the Success of Corporate Sustainability Programs: A Case Study Approach

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Abstract

The chapter examined the impact of employee engagement on the success of corporate sustainability programs, using a case study approach. In the pursuit for sustainable growth, businesses increasingly realise the importance of including sustainability in their basic functions. This study examines the vital significance of employee participation in the effectiveness of business sustainability initiatives. This study uses a case study methodology to analyse firms that have successfully included their staff in sustainability efforts. The research uncovers the principal variables incentivising employee participation in these programs. The techniques organisations utilise to enhance such engagement and the consequent influence on the overall efficacy of sustainability initiatives. The results indicate that elevated employee involvement markedly improves the effectiveness of sustainability initiatives. Motivational variables, including personal beliefs, company culture, and leadership support, are essential in fostering employee engagement. Moreover, effective communication, rewards, and recognition are optimal for promoting participation. The case studies demonstrate that firms with engaged workers attain their sustainability objectives more effectively while enhancing employee morale and overall organisational performance. This research elucidates the role of employee engagement in achieving corporate sustainability goals, offering critical insights for firms seeking to improve their sustainability efforts through active employee participation.

Keywords: employee engagement, organisational performance, communication, development, culture, leadership support

1. Introduction

The chapter examined the impact of employee engagement on the success of corporate sustainability programs using a case study approach. Engaging the workforce in goal setting fosters group ownership and commitment, making success apparent and concrete. It involves establishing a collective vision for the company's sustainability goals and acknowledging each individual's contribution to realising

these aims. In pursuing sustainable growth, organisations increasingly recognise the significance of integrating sustainability into their core operations [1]. This study examines the significance of employee involvement in the effectiveness of corporate sustainability programs.

Sustainability has become essential to company strategy in the contemporary, swiftly changing business environment. Companies are becoming increasingly aware of their environmental and social responsibilities, endeavouring to incorporate sustainable practices into their operations [2]. The efficacy of these sustainability initiatives frequently depends on the degree of employee involvement [2]. Engaged employees are more likely to endorse and actively participate in activities that promote environmental stewardship and social responsibility, thereby enhancing the efficacy of these programs.

This study investigates the impact of employee involvement on the effectiveness of business sustainability initiatives, employing a case study methodology to provide a thorough examination. This study identifies the motivational factors, tactics, and outcomes associated with increased employee engagement in sustainability initiatives by analysing firms that have effectively incorporated their workforce. The introduction establishes the framework for examining the influence of personal beliefs, corporate culture, and leadership support on employee motivation. It highlights the importance of effective communication, incentives, and recognition in fostering involvement.

This research aims to demonstrate, through comprehensive case studies, that firms with engaged workers achieve their sustainability objectives more effectively while simultaneously experiencing improved employee morale and overall organisational performance. Understanding the dynamics of employee participation in sustainability projects is crucial for firms aiming to enhance their sustainability initiatives. This study offers valuable insights into effective practices and techniques for cultivating a culture of sustainability within enterprises, thereby advancing the overarching goal of sustainable development.

Research questions

- What motivating variables compel employees to engage in business sustainability initiatives?
- In what ways do personal values, corporate culture, and leadership support impact employee motivation?

These research questions guide the study and facilitate an understanding of the pivotal role of employee involvement in the effectiveness of business sustainability initiatives.

2. Literature consideration

Employee engagement in sustainability extends beyond mere participation, encompassing the complete involvement, steadfast dedication, and proactive contributions of employees to sustainable practices within a business. It seamlessly incorporates sustainability ideas and projects into the core of workplace culture while actively engaging employees in environmental, social, and economic sustainability endeavours [1]. Employees are essential in promoting sustainable practices inside a firm. By actively utilising their skills, creativity, and steadfast commitment, companies can

foster a thriving culture of sustainability. They can achieve substantial advancements in environmental conservation and social welfare through coordinated endeavours.

Although the importance of sustainability for firms is widely recognised, many struggle to include every employee in their daily sustainability initiatives properly. It is essential to identify new strategies that motivate and empower personnel at all organisational levels, cultivating a collective dedication to sustainability. In the contemporary, swiftly evolving landscape, sustainability has emerged as a pivotal concern for enterprises striving to secure enduring success while mitigating adverse effects on society and the environment [1]. Employee collaboration is receiving heightened acknowledgment for its essential contribution to promoting organisational sustainability.

When cooperation is integral to an organisation's culture, it fosters innovative, efficient, and comprehensive strategies for sustainability, including social, environmental, and economic aspects [3, 4]. Sustainability is an increasing issue for corporations, scholars, legislators, and worldwide organisations alike. This issue is evident in the expanding literature across all disciplines, investigating how businesses might incorporate sustainability into their operations [5, 6]. The complexities of sustainability necessitate ever advanced solutions. Employee collaboration is essential for attaining sustainability objectives [7].

2.1 Collaboration across organisational levels

A collaborative culture promotes knowledge exchange, interdisciplinary cooperation, and innovation. These elements are crucial for formulating sustainable approaches that can tackle intricate, long-term difficulties [8]. For instance, minimising waste, enhancing energy efficiency, and extending product life cycles are all endeavours that gain from collaborative problem-solving and pooled expertise. Organisations that include collaboration into their corporate culture are more inclined to devise solutions that integrate sustainability into daily operations, resulting in more sustainable outcomes [9, 10].

Sustainability comprises several dimensions: environmental, social, and economic. Organisations must implement strategies that reduce their ecological footprint, including emission reduction, resource conservation, and pollution mitigation [11]. Sustainability, in a social context, pertains to equitable labour practices, diversity, community involvement, and the welfare of employees. It requires that firms maintain financial viability while safeguarding future resources [12–15]. To attain these intricate objectives, the internal culture of firms must transform, prioritising cooperation, shared accountability, and joint effort [16, 17].

Collaboration across all organisational levels is essential for promoting innovation in sustainability initiatives [18–20]. A hierarchical method of problem-solving frequently leads to compartmentalised thinking and an absence of a comprehensive perspective [21–23]. Conversely, when personnel from other departments interact, they provide distinct viewpoints and knowledge, resulting in more thorough and effective solutions. A robust culture of cooperation fosters open communication, flexibility, and a readiness to explore innovative concepts, all of which are essential for sustainability [24].

To maintain competitiveness in the contemporary globalised and environmentally aware market, firms must embody the traits of a learning organisation [25]. A learning organisation is one that perpetually evolves, assimilating new knowledge, responding to changes, and fostering continual progress. In the realm of sustainability, this entails embracing innovative technologies, practices, and policies that

promote ecological balance, social equity, and economic growth [26, 27]. It also entails the development of personal mastery among employees, signifying that individuals are driven to enhance both their professional and personal skills [28, 29].

Collaboration is a fundamental component of a learning business, where individuals exchange information and collaborate to create lasting solutions [30–32]. This necessitates the establishment of an open culture that encourages employees to articulate ideas, experiment with novel methodologies, and participate in ongoing learning [33–36]. Leadership has a vital role in cultivating this climate. Leaders must exemplify collaborative conduct and establish frameworks and procedures that promote cooperation [36–39]. They must also underscore the significance of sustainability in corporate objectives and motivate employees to contemplate the long-term consequences of their activities rather than only short-term benefits [40, 41].

Although the advantages of collaboration are evident, cultivating a culture of cooperation inside businesses presents some hurdles. A principal impediment is the conventional hierarchical framework of several companies, which may obstruct open communication and the unrestricted exchange of ideas. Employees may hesitate to share knowledge or cooperate if they believe it might threaten their own success or if they feel their efforts are undervalued. Surmounting these obstacles necessitates a transformation in organisational mentality and leadership that emphasises communal success rather than individual accomplishments [42].

Moreover, the escalating demands placed on employees, regarding both workload and the desire for cross-functional collaboration, may result in burnout and tiredness. This is especially applicable in companies without essential support structures, such as defined collaborative procedures or recognition frameworks that reward collective accomplishments [43]. The well-being of employees is essential for promoting enduring collaboration, and firms must confront these problems to cultivate a culture of sustainability.

2.2 Corporations on sustainability activity

A further difficulty is the incorporation of sustainability within the current organisational framework. Numerous corporations perceive sustainability as an isolated activity, often managed by a designated department, such as the corporate social responsibility (CSR) department [44, 45]. To attain genuine sustainability, it must be integrated into all facets of the firm, encompassing supply chain management, marketing, and human resources [46, 47]. This necessitates extensive coordination and communication among departments, along with a mutual comprehension of sustainability objectives [48]. Stakeholder theory has been utilised in sustainability and cooperation research, emphasising the necessity for companies to account for the interests of all stakeholders, both internal and external, in their decision-making processes [49].

The correlation between employee collaboration and sustainability has been extensively demonstrated. Organisations that cultivate a robust collaborative culture are more likely to achieve success in their sustainability initiatives. Collaboration fosters inventive ideas and bolsters employee involvement and dedication to business objectives [50]. Employees exhibit heightened motivation to engage in sustainability projects when they perceive themselves as integral members of a team striving towards a shared objective.

Moreover, a collaborative culture fosters resilience among enterprises. The difficulties of sustainability, including climate change and resource constraint, are intricate and uncertain [51]. Organisations that promote cooperation are more adept

at adapting to difficulties, since they may leverage the pooled knowledge and skills of their workforce [52]. Adapting and innovating is essential for sustained success in a swiftly evolving environment.

Collaboration among employees is essential for the execution of sustainability initiatives [53]. For these policies to be effective, they must be adopted by employees at every level of the firm. A collaborative culture guarantees that employees are actively involved in both policy creation and execution. This involvement fosters heightened knowledge of sustainability concerns and a more robust dedication to tackling them [54].

This literature study comprehensively examines the complex aspects of employee collaboration and sustainability. This evaluation highlights the essential components pertinent to operational sustainability to guarantee alignment with the study's emphasis. This study specifically focuses on how adaptive leadership, multidisciplinary teamwork, and digital technologies facilitate the cooperation to achieve sustainable results. This research differentiates itself from previous studies by focusing on these characteristics, examining general cooperation behaviours, and offering concrete methods suited to various organisational situations. This research expands on prior studies that thoroughly examine the theoretical foundations of cooperation and its possibilities by providing a practical and scalable framework.

The suggested model distinctly combines environmental, social, and economic sustainability aspects with organisational culture and leadership dynamics. This technique connects theoretical frameworks with practical applications, fulfilling the urgent demand for implementable strategies in the domain. The scientific literature on sustainability goals consistently underscores that participation in the sustainability program involves individual businesses and every employee [55]. This framework creates an opportunity for collective engagement [56], enabling mutual recognition and resolution of sustainability challenges while fostering collaboration to effectuate desired transformations. This research seeks to establish a comprehensive conceptual framework for employee participation in advancing organisational sustainability, incorporating environmental, social, and economic aspects.

3. Research methodology

3.1 Research design

Since the research design specifies the steps to take and the data to gather, it is essential to pick a legitimate and suitable design to get trustworthy results [44]. Research design is the methodical framework for gathering data. This study used a correlation design because the researcher was interested in the connection between work motivation and employee engagement. This study utilises a qualitative case study technique to investigate the critical importance of employee involvement in the efficacy of corporate sustainability programs. The case study method facilitates a comprehensive examination of particular firms that have effectively included their employees in sustainability initiatives.

3.2 Selection of cases

Choosing a case study methodology requires specific criteria to guarantee that the research is rigorous, representative, and capable of producing significant insights.

The case study was selected to ensure pertinence to the research questions. The cases must be directly pertinent to the study issues or hypotheses under examination. This guarantees that the study tackles the fundamental issues and offers significant insights. Using a case study requires representativeness; the chosen instances exemplify the wider population or phenomena under investigation. This facilitates the generalisation of findings and comprehension of the broader context.

For adaptation, the study incorporated instances that demonstrate variation in essential factors, which helps enhance understanding of the phenomenon. This may entail the selection of representative, diverse, extreme, deviant, influential, most similar, or most different examples. Using a case study requires practical factors, such as data availability, location accessibility, and the practicality of conducting comprehensive study, which are essential.

Criteria for selecting cases:

- Organisations with established and acknowledged sustainability initiatives.
- Proven effectiveness in including workers in environmental projects.
- Diversity among industry sectors facilitates a thorough comprehension across various situations.

Sampling technique:

- *Purposive sampling*: Choose firms based on their esteemed reputation and recorded achievements in sustainability initiatives.
- *Snowball sampling*: Employ referrals from first-case organisations to pinpoint other pertinent cases.

3.3 Motivation for selecting case study companies

The selection of companies for this research is driven by the need to explore diverse, real-world examples where employee engagement plays a pivotal role in the success of corporate sustainability initiatives. The following criteria guided the selection process:

3.3.1 Demonstrated commitment to sustainability

Companies were chosen based on their publicly documented sustainability programs, including Environmental, Social, and Governance (ESG) reports, sustainability rankings, and third-party certifications (e.g., LEED, B Corp, ISO 14001). This ensures that the organisations have mature and measurable sustainability efforts in place.

3.3.2 Evidence of employee engagement practices

Selected companies have a track record of fostering employee involvement through initiatives such as green teams, sustainability training, employee-led innovation programs, and internal sustainability challenges. This allows for a meaningful analysis of how engagement strategies influence outcomes.

3.3.3 Industry and geographic diversity

To enhance the generalizability of findings, companies from different sectors (e.g., manufacturing, technology, retail, and services) and regions were included. This diversity helps uncover sector-specific dynamics and cultural influences on engagement and sustainability.

3.3.4 Availability of data and access

Practical considerations such as access to internal documents, employee surveys, interviews, and sustainability performance metrics were essential. Companies that were open to collaboration or had sufficient publicly available data were prioritised.

3.3.5 Recognition and awards

Inclusion of companies recognised for excellence in sustainability and employee engagement (e.g., inclusion in the Dow Jones Sustainability Index, Great Place to Work rankings) provides validated examples of best practices.

3.3.6 Comparative value

Some companies were selected to provide contrast—for example, comparing high-engagement vs. low-engagement environments or different stages of sustainability program maturity. This comparative approach enriches the analysis and highlights key success factors.

3.4 Methods of data collection

3.4.1 Fundamental data

During the analysis, the collected data examined company reports, sustainability strategies, and employee engagement surveys to gather both quantitative and qualitative information about sustainability activities and employee involvement.

Review of literature: The study also examines current literature on employee engagement and sustainability to situate findings within wider theoretical frameworks, using keywords. The study accessed and reviewed relevant literature through advanced search from different databases such as Google scholar and Scopus.

3.4.2 Data examination

Comparison of cases: Analyse data from many firms to discern shared trends and distinctive techniques that enhance employee participation in sustainability initiatives.

3.4.3 Adoption of the case study approach

The study adopted a case study methodology that entails a comprehensive analysis of a particular instance, such as an individual, group, organisation, event, or phenomena, to elucidate intricate concerns within a real-world setting. It emphasises extensive, meticulous data collecting, and analysis to offer a thorough comprehension

Articulate the research question and objectives	The study explicitly defines the aims and goals of your research and devises a specific research question that directs the study.
Select the case	Choose a case that corresponds with your study aims and offers substantial and nuanced data. Evaluate aspects such as the case's pertinence, accessibility, and the capacity for yielding meaningful conclusions.
Formulate a research protocol	Detail the protocols for data collecting, encompassing techniques such as interviews, observations, document analysis, and archival records. It establishes case limits to maintain focus and prevent scope expansion.
Data collection:	Collect data from several sources to improve the validity and dependability of your research. Employ varied data collecting techniques to attain a thorough comprehension of the situation.
Analyse and interpret data	Conduct a comprehensive analysis of the data to discern patterns, themes, and linkages. Analyse the results in relation to your research topic and the current body of literature.
Present the results	Articulate the case study results in a lucid, succinct, and comprehensible format. Emphasise the principal findings derived from the research and connect them to overarching theoretical paradigms or practical implementations.

Table 1.
The case study approach.

of the situation. Here is an analysis of the methodology for employed by the study for the case study approach (**Table 1**).

3.4.4 Constraints

Limit: The research concentrates on a restricted selection of example organisations, which may not accurately reflect all sectors or geographic areas.

Subjectivity: Researcher bias may affect qualitative data analysis; measures will be implemented to alleviate this through triangulation and member verification.

3.5 Data presentation and discussion of research findings

The presentation and analysis of research findings entails the visual display and interpretation of data gathered during the study to convey insights and conclusions to an audience. Data presentation in a study used visual aids such as graphs and charts to systematically arrange and elucidate information, hence enhancing comprehension. The study used tables to present the data of case studies. The discussion explores the significance and ramifications of these discoveries, linking them to overarching research inquiries and established knowledge.

Research questions

- What motivating variables compel employees to engage in business sustainability initiatives? (**Table 2**)

Case study 1: Patagonia.

Case study 2: Lyft (**Table 3**).

Case study 3: Nike (**Table 4**).

These case studies demonstrate that the confluence of corporate culture, leadership endorsement, employee empowerment, risk management, and stakeholder

Corporate culture and values	Patagonia's profound dedication to environmental sustainability is intricately woven into its company culture and values. The creator of the firm, Yvon Chouinard, has consistently underscored the significance of environmental preservation, a sentiment that resonates with employees who hold analogous ideals.
Employee empowerment	Patagonia promotes employee involvement in environmental advocacy and provides chances for engagement in sustainability initiatives. This empowerment cultivates a sense of ownership and pride among employees.
Recognition and rewards	The organisation acknowledges and compensates workers who participate in sustainability projects, hence enhancing their motivation to engage in these activities.

Table 2.
Motivating variables for Patagonia.

Corporate mission alignment	Lyft's purpose to enhance lives <i>via</i> superior transportation is congruent with its sustainability objectives. Employees are inspired by the organisation's dedication to decreasing carbon emissions and advocating for renewable energy.
Community impact	Lyft's sustainability initiatives, including carbon-neutral rides, foster a beneficial effect on both the community and the environment. Employees are inspired by the concrete advantages their labour provides to society.
Leadership endorsement	Robust backing from leadership for sustainability projects guarantees that workers perceive their contributions as esteemed and endorsed at the top echelons of the organisation.

Table 3.
Motivating variables for Lyft.

Risk management	Nike's sustainability activities are partially motivated by the necessity to mitigate risks related to environmental and social concerns. Employees recognise that participating in sustainability initiatives mitigates risks and secures the company's long-term viability.
Innovation and creativity	Nike promotes innovation in sustainability, enabling employees to devise creative solutions to environmental issues. This cultivates a culture of invention and perpetual enhancement.
Stakeholder pressure	External influences from stakeholders, including as consumers, investors, and regulatory entities, compel staff to participate in sustainability projects to fulfil these expectations

Table 4.
Motivational factors.

influence are important motivational factors that drive workers to participate in business sustainability projects. The outcomes of Patagonia Initiatives established *Fair Trade Program*, whereby more than 90% of Patagonia's goods are manufactured in Fair Trade Certified™ facilities, helping over 85,000 workers [57].

In terms of Lyft Initiatives, the organisation provides carbon-neutral trips by compensating for the emissions generated by its transportation network. They also established the *Sustainability Dashboard* that was introduced in the Lyft Business Portal; this dashboard helps enterprises monitor and mitigate their carbon impact resulting from ridesharing services. The LyftUp Initiative was another remarkable initiative that offers economical transportation to underprivileged communities, facilitating access to vital services. The organisation also established the Driver Support Programs.

Nike Initiatives established the Move to Zero program, which aimed to achieve zero carbon emissions and zero waste, focusing on reducing greenhouse gas

emissions, waste, and water consumption, as well as enhancing chemical processes. Circular Solutions is another initiative that repurposes existing plastics, fibres, and fabrics, and innovates new materials to minimise waste.

The organisation also established Sustainable Innovation, which expands sustainable technologies across the enterprise to mitigate the environmental effects. These initiatives exemplify each company's dedication to sustainability and their endeavours to involve employees in significant environmental practices.

Research questions

- In what ways do personal values, corporate culture, and leadership support impact employee motivation?

In responses to the above research questions, there are three case studies that illustrate how personal values, corporate culture, and leadership support impact employee motivation.

Case study 1: Patagonia

Personal values: Patagonia, an outdoor apparel and equipment company, is distinguished by its strong commitment to environmental sustainability. Yvon Chouinard, the founder of the company, has instilled principles of environmental stewardship and ethical business practices within the organisation.

Effect on employee motivation:

Personal values: (**Table 5**).

Case study 2: Zappos.

Zappos, an online retailer of footwear and apparel, is renowned for its distinctive and dynamic company culture. The organisation prioritises staff satisfaction and client service.

Effect on employee motivation:

Organisational culture (**Table 6**).

Case Study 3: Google.

Google is recognised for its creative and supportive leadership approach. The organisation's executives emphasise employee welfare and cultivate a culture of perpetual learning and advancement.

Effect on employee motivation (Table 7).

These case studies illustrate that individual values, organisational culture, and leadership endorsement are essential in influencing employee motivation. By connecting these variables with employees' requirements and ambitions, organisations may cultivate a motivated and engaged workforce.

Value Alignment	Employees who possess analogous environmental values are significantly motivated to work at Patagonia, perceiving a congruence between their values and the company's mission.
Sense of Purpose	The organisation's commitment to sustainability initiatives, including the Fair-Trade Program and Regenerative Organic Certified Cotton, which instils a sense of purpose and pride in employees' work.
Employee Engagement	Patagonia's values-centric culture fosters elevated levels of employee engagement and loyalty, as employees are motivated by the prospect of making a positive environmental impact.

Table 5.
Personal values.

Empowerment and Autonomy	Zappos grants its workers the authority to make decisions and do activities that improve customer satisfaction, so enhancing their motivation and job fulfilment.
Positive Work Environment	The organisation's enjoyable and inclusive culture, characterised by team-building activities and a casual dress code, fosters an excellent work atmosphere that inspires individuals to excel.
Recognition and Rewards	Zappos acknowledges and compensates employees for their contributions, thereby augmenting their drive and dedication to the company's objectives.

Table 6.
Organizational culture.

Supportive leadership	Google's leaders offer assistance and resources to employees in achieving their professional and personal objectives, therefore augmenting their motivation and job happiness. Three.
Opportunities for growth	The organisation provides many avenues for professional advancement, including training programs, mentorship, and the autonomy to pursue passion projects, therefore incentivising employee excellence.
Transparent Communication	Google's leadership fosters transparent communication and feedback, creating an inclusive work environment that inspires people to present their best ideas and efforts.

Table 7.
Leadership endorsement.

4. Results and discussion of research findings

The results from the case studies on employee engagement in Corporate Sustainability Initiatives show that employee participation is a vital element in the efficacy of business sustainability initiatives [58]. When employees are engaged and motivated, sustainability programs are more likely to achieve their objectives and have lasting positive effects. The next section examines the multifaceted dimensions of employee participation within business sustainability initiatives through case studies as an essential method for data collection.

5. Impact on employee engagement

The results on Patagonia case study selved into value alignment, and it was noted that employees are motivated by the company’s strong environmental beliefs, leading to increased engagement. In terms of empowerment, the employees are incentivised to participate in sustainability efforts, fostering a sense of ownership. Remunerating employees for their contributions enhances motivation and retention.

The results from the Lyft organisation were linked to intentional motivation and indicated that employees are motivated by the organisation’s commitment to reduce carbon emissions. The beneficial effects on the community and environment enhance employee pride and engagement. Leadership Endorsement also shows positive outcomes. The study found that strong leadership support cultivates a sense of worth and drive among employees.

Results from Nike were linked to risk mitigation, whereby employees acknowledged the need for sustainability in risk management, leading to heightened

Increased Productivity and Innovation	Engaged personnel exhibit heightened productivity and dedication to their tasks. They introduce innovative and inventive solutions to sustainability concerns, fostering continuous growth within the firm.
Favourable Brand Reputation:	Organisations exhibiting elevated employee involvement in sustainability are seen more positively by customers, investors, and stakeholders. This improves the company's reputation and market competitiveness.
Elevated Retention Rates:	Engaged workers exhibit more satisfaction and loyalty, resulting in decreased turnover rates. This consistency is essential for sustaining momentum in sustainability programs.

Table 8.
Significance of employee engagement.

engagement. In terms of innovation culture, findings show that fostering creativity and continuous improvement nurtures an engaged workforce. Furthermore, stakeholder satisfaction is vital because meeting stakeholder expectations enhances employee pride and commitment (**Table 8**).

6. Holistic impact on corporate sustainability initiatives

The research demonstrates that employee engagement in the sustainability of organisational initiatives can enhance productivity, because engaged employees demonstrate elevated productivity and commitment to achieving sustainable goals. Employee engagement in sustainability initiatives cultivates innovative solutions to environmental issues [2]. Furthermore, organisations that engage staff in sustainability activities are seen more favourably by customers, investors, and stakeholders.

The findings from the case studies demonstrate that employee participation is crucial for the effectiveness of business sustainability initiatives. By aligning personal values, corporate culture, and leadership support with sustainability goals, companies can develop a motivated and engaged workforce that promotes positive environmental and social outcomes.

6.1 Promoting organisational sustainability *via* employee collaboration

This chapter offers an extensive analysis of how employee cooperation may enhance organisational sustainability across environmental, social, and economic aspects. It highlights the importance of flexible leadership, multidisciplinary teams, and digital technology in enhancing employee engagement. Employee cooperation is essential for fostering organisational sustainability through improved efficiency, creativity, and resilience [59]. Operational sustainability is achieved when economic, social, and environmental objectives are pursued in a manner that fosters a culture of employee participation.

By matching these objectives with collaborative practices, companies may establish a positive feedback loop in which sustainability efforts enhance collaboration, and collaboration propels the success of sustainability programs. This comprehensive strategy facilitates the establishment of a more robust, efficient, and socially accountable organisation that can prosper over the long run. Enhancing a culture of employee

cooperation to attain sustainability necessitates fostering an atmosphere where sustainability is a collective concern and collaboration is standard practice [60].

By integrating sustainability objectives with cooperative practices, equipping staff with appropriate tools and training, and acknowledging the significance of teamwork, businesses may cultivate a robust, resilient culture that promotes operational sustainability and facilitates long-term success. This analysis identifies critical inadequacies that hinder the effective integration of cooperation and organisational sustainability, despite the existing literature's thorough examination of their relevance.

Many studies highlight the importance of trust and communication inside teams but fail to clarify how these essential elements develop into broader practices, such as cross-departmental collaboration and stakeholder involvement [61]. Furthermore, the emphasis on adaptable leadership fills a notable need in the current literature. Previous studies often characterised leadership as static; however, this study demonstrates that leadership must be dynamic, serving as a mediator between corporate culture and sustainability activities.

Adaptive leadership facilitates the conversion of collaborative efforts into actionable solutions, ensuring that sustainability goals are not only stated but also achieved in practice. The impact of emerging technologies, like artificial intelligence and blockchain, on enhancing cooperation and transparency in businesses is a significantly underexplored area with considerable potential [62]. The framework highlights the contribution of each idea to sustainability goals by matching theoretical constructs with practical consequences.

Cultivating trust and transparent communication among teams fosters a culture of collective accountability, which is vital for collaborative problem-solving. Interdisciplinary cooperation utilises this basis to devise new solutions, including minimising resource waste and improving operations [1, 2]. These endeavours are enhanced by strategic leadership and involvement with external stakeholders, hence assuring the scalability and institutional backing of sustainability programs [3, 4, 63].

This systematic case study approach elucidates the interconnections between ideas and provides pragmatic insights for businesses seeking to enhance cooperation and sustainability initiatives through employee engagement. In summary, employee participation is an essential element of effective company sustainability initiatives. By harmonising personal beliefs, company culture, and leadership endorsement with sustainability objectives, organisations may cultivate a motivated and engaged workforce that fosters beneficial environmental and social outcomes.

The case studies of Patagonia, Lyft, and Nike illustrate that employee engagement and motivation significantly enhance the likelihood of success in sustainability programs, resulting in enduring beneficial effects.

7. Concluding remark

Collaboration to facilitate meaningful change is imperative. Organisations are acknowledging the significance of uniting employees around common objectives and principles. Creating a sustainability employee resource group is an excellent method to enhance collaboration and advance sustainability. This chapter explores the impact of employee engagement on the success of corporate sustainability programs using a case study approach, looking at how it might leverage cooperation to effectuate positive change inside businesses.

Creating a sustainability employee resource group may harness employees' enthusiasm for sustainability, establishing a forum for idea exchange, project execution, and company policy influence. This collaborative endeavour fosters a culture of environmental accountability inside the organisation and contributes to attaining long-term sustainability objectives.

Additionally, creating a sustainability employee resource group may be a significant asset for workers, offering avenues for education, networking, and personal development. Using its members' pooled knowledge and skills, it may provide training programs, workshops, and educational events that enable employees to serve as ambassadors for sustainability in their professional and personal spheres.

In conclusion, creating a sustainable employee resource group may catalyse beneficial organisational transformation. Through cooperation, promoting sustainability projects, and empowering employees, these groups make a significant contribution to their enduring influence both within and outside the broader community.

Conflict of interest

The author declares no conflict of interest.

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Tradition and Innovation: Ecologies of Sustainable Learning in Contemporary Craft Work

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Abstract

Craft work is undergoing significant transformations related to integrating emerging technologies, affecting professional practices, knowledge transmission and the sustainability of workplaces. These changes require new organizational structures and skills capable of combining digital innovation and tradition. In an evolving labor market characterized by challenges to the traditional knowledge transmission between master craftsmen and apprentices, the paper analyzes the impact of technologies on craft practices and situated learning within communities of practice. This analysis is grounded in a narrative literature review informed by a critical and interpretive methodological approach. The focus is on creating sustainable learning ecologies that balance technological innovation, social inclusion and cultural enhancement. The analysis highlights the need to develop learning environments that support the adaptation of traditional skills to contemporary challenges. In conclusion, it stresses the importance of maintaining a balance among technology, learning and sustainability to ensure the continuity and evolution of craft work.

Keywords: craft work, learning ecologies, situated learning, sustainable learning, tradition and innovation, future of work

1. Introduction

Craftwork has become of renewed interest in recent years [1–4]. Industries like these—the so-called “neo-artisanal” makers, roasters, brewers, potters, distillers, barbers, tattooists and artisan butchers—have become a legitimate economic sector in the modern economy. This is, somehow, explained by the doctrine of authenticity as a cultural object of value that provides distinction, significance and acknowledgment [3, 5–7].

This re-evaluation of craftsmanship cannot be indiscriminate to the new technologies and to cultural and social changes. In this sense, the chapter seeks to identify how sustainable learning ecologies can be a means of balancing tradition and innovation.

The aim is to secure the longevity of craft with processes that celebrate heritage and marry that with the challenges of a fast-paced and constantly evolving society.

The overlap of the digital and the artisanal has moved into the foreground as a strong focus on how new technologies play a role in changing traditional modes of working, with significant implications for culture and the economy [8, 9]. Digitalization, as the spread of digital tools in society, has played a considerable role in the artisans' sector, providing new instruments and processes for the creation, usage and consumption of objects [10, 11]. Digitalization, within the context of contemporary crafts provides challenges and opportunities for artisans and their communities [12, 13].

So, Sennett [14] claims, in fact, all skills, even the most abstract, are rooted in bodily activities. Technical insight comes by imagination, not by practiced skill. The hand, in its manipulation of the object, becomes the principal instrument of knowledge, while the spirit may let itself go into the imagination of the possibilities that materials and tools offer. This learning technique, informed by raw materials organic resistance and ambiguity, causes the artisan to build on and transcend their craft skills.

Therefore, craftsmanship is set in opposition to industrial and standardized production and presents itself as an alternative, based on manual skills, creativity and a very close relationship to materials. While Sennett suggests, craftsmanship designates “a distinctive human condition of activity” that can imply ways of tool use, of bodily movement, of thinking about materials, and as such would provide a contrasting model for life and production, the bodily withdrawal of ourselves and our hands under modernity.

The idea that technology encodes technical skill, just as writing encodes the art of speech, is a perspective that distorts the true nature of skill. Skill does not consist of acquired mental representations or cognitive models, but of embodied capacities for attention and response, developed over time. Skilled practice is not simply the application of mechanical force to external objects, but involves care, judgment and dexterity qualities. It implies that what practitioners do with things is grounded in attentive, perceptual engagement with them, that is, they observe and feel as they work [15].

In this view, craftsmanship is grounded in three essential faculties: identification, interrogation and disclosure. The first is to discover the materials, the second is to meditate on them, and the third is to increase them. These are not just skills relating to making things but also to human relationships—of learning to play nicely with others, share ideas, and get along with other people in general.

The meeting of the new technology and the old craft is a potential challenge and opportunity, especially in the support for learning and knowledge transmission. In this evolving context, the notion of sustainable learning ecologies is suggested as a transitional stage that embraces traditional practices and values while being eventually combined with digital and high-tech enablers [14, 16]. Indeed, access to newer technologies (such as 3D printing and augmented reality (AR)) in addition to newer design software (digital design tools) gives craftspeople opportunities to develop original ways of creating and making, which include functional qualities, together with an openness in preserving artifactual, as well as cultural significance within their work [17, 18]. This model not only keeps alive the legacy of craft but, at the same time, brings it to the hands of the new generations of artisans to trust in the survival of the sector in a fast-changing world [19].

As defined by Campbell [18], craftsmanship is the personal expression of the maker where the personal traits are evident. This direct relationship between the

craftsman and his product gives each piece that special touch and positive energy, making it into a celebration of individualism and artistry.

The future of work in the digital age, as work changes, the craft sector is on an unprecedented cusp of change. Incorporating 3D printing, artificial intelligence and digital e-commerce platforms is changing the concept of being a craftsman for the twenty-first century [20, 21]. On the one hand, they shape new possibilities for market extension, product individualization and production upgrade. On the other hand, they pose questions of the depreciation of handmaking, the rapid reduction in skill-based techniques and the authenticity of craft-made products [22, 23].

The next phase of craft will unfold by walking a fine line between the advancement of technology and the preservation of culture. Though the modern age has introduced the availability of a range of digital options, these opportunities are not without their challenges and risks regarding maintaining an authentic craftsmanship tradition. This blend of manual and digital traditions reshapes not only the work character but also the economic and cultural aspects of the craft field [10, 13].

Sustainable learning ecologies are a useful concept to do so in relation to the complexity of technological integration in craft. These ecologies provide the overall context in which knowledge, skills and competencies can supportably develop. They mediate between tradition and innovation so that traditional practice can continue and new methods and sophisticated tools can also be considered.

According to Väänänen [24], craft is an ecology of culture embodied in the needs, desires, values, attitudes, tastes and functions of society. This point of view highlights the place of art, craft and design [25], and implies how sustainable learning ecologies in craft work should consider these differing dimensions. Between tradition and innovation is a conversation about maintaining traditional cultural practices and integrating new design and technology philosophies, so the craft sector can be sustainable in the modern world.

Within this framework, this chapter is concerned with exploring ways in which sustainable learning ecologies can act as a bridge between tradition and innovation, in order to keep the values and skills of the craft trades alive in a modern world. We will discuss how these tools can be employed in ways that maintain cultural heritage, contribute to social inclusion and support creativity by exploring the relationship between digital technologies and craft practice.

2. Methodology

This chapter employs a narrative literature review to make sense of the complexities by which hybrid learning ecologies have entwined tradition, digital innovation and sustainability in contemporary craft. As an emerging interdisciplinary domain of knowledge at the crossroads of material culture, education, technology and sustainability, it is doubtful that only a systematic or quantitative treatment would offer enough to capture the depth of context and conceptual diversity at stake.

Narrative reviews enable comprehensive and integrative reflection on the state of knowledge. They are thus particularly suitable if the aim is not only to collect information but to interpret, synthesize and propose conceptual models based on different sources. This strategy resonates with contemporary methodological discussions around interpretive reviews for craftwork, digitalization and learning, particularly when research areas are fragmented or epistemologically plural.

In this chapter, we seek to trace the genealogy of ideas, site empirical detail and propose a unique framework—Hybrid Artisan Learning Ecologies—to describe the complex interactions between the analog and digital within craft-based learning. To ensure methodological rigor, we carried out target searches in the most significant academic databases—Scopus, Web of Science and Google Scholar—using as keywords of interest “learning ecologies,” “digital craft,” “sustainability in craft,” “tradition and innovation,” “communities of practice,” “hybrid learning” and “workbased learning.” These search terms were chosen to capture the multidimensionality of the field, enabling sources to be included from education, design, anthropology and critical technology studies.

The inclusion criteria were defined based on peer-reviewed journal articles, books and chapters (a) focused on the relationship between technology and craft, (b) referred to the issue of learning, sustainability or cultural transmission, and (c) provided empirical or strong theoretical lens. Descriptive or non-analytical sources on learning processes were omitted.

For each reference, the theoretical orientation and methodological approach, country/culture and its engagement with tradition, digitalization, pedagogy and sustainability were examined. This thematic coalescence and conceptual synthesis informed the development of the five dimensions constituting the framework—multimodality, distributed learning, learner agency, expanded embodiment and problem-driven reflection—key areas of study. The main research questions are: what can learn ecologies do to manage the tradition and innovation tension in artisan designs? How do you negotiate the pedagogical and cultural requirements that enable the incorporation of digital tools without jeopardizing the sustainability and authenticity of craft? What does it mean for craft learning to be embodied, community-based and transformative in the digital era?

This chapter does not intend to end debates but to open up conceptual spaces to think pedagogically and politically about craft in a world in the making. By critically and reflexively engaging with literature, we contribute theoretically while informing educators, craftspeople, researchers and policymakers who share a concern for maintaining craft as a vibrant cultural and educational way of life.

3. Analysis: Challenges and potentials in contemporary craft practice advancements in the craft industry with digitalization

3.1 Advancements in the craft industry

Over the past decade, the craft industry has undergone major changes, primarily driven by digitalization and technological advancements. All are changes that have affected traditional craft techniques and practices, where many challenges to the preservation of cultural heritage can be both obstacles and newfound opportunities for many artisans. Digital technologies have changed the making, selling and consumption of crafts on many fronts, thereby widening both the access to craft and encouraging diversification in terms of genre. In this piece, we will be analyzing the influence of digitalization on craft and traditional techniques, examples of digital innovation in craft practice, and the balancing act for artisanal heritage following digitization.

Traditional craft techniques have been revolutionized in the digital age. For centuries, artisans have used experience handed down from generation to generation

as a basis for their products [24]. In the twenty-first century, due to the integration of digital technology, artisans are exploring hybrid forms that are part craft and part technology. These new tools provide infinite precision and control, allowing one to create designs and patterns previously challenging, if not impossible, to do. Computer-aided design (CAD) software, for example, allows artisans to digitally see and alter a design they have started, thus allowing for creative exploration of new ways to create without risking excess material.

The digital also has an archival function when it comes to maintaining in a recorded format, traditional processes of craftsmanship for posterity. This record keeping ensures that the old ways are not forgotten and that the knowledge can be up to date, kept current, along with new technologies. Illeris and Riis [26] highlight that digitalization is a chance to link education and ecology/nature, thus showing sustainability in craft practice indicators. With the help of digital tools, artisan can conserve their cultural heritage and fit into their traditional evolution in the modern market as market demands.

Digital technology has played a crucial role in the development and reshaping of craft processes, providing opportunities for both expression and production. In this context, 3D printing is one such technology that has revolutionized traditional methods, allowing craftsmen to design complex building forms that previously could not be achieved [27]. For example, a jewelry designer can produce detailed and intricate designs that minimize the waste of material.

Uncanny as it may sound, one of the most influential innovations is digital platforms being used for selling craft products. Both online marketplaces and social media channels not only widen the reach of artisans but also provide them with a chance to communicate with a global audience. Being online and having this digital presence not only adds to sales opportunities but also builds a community for artisans as well as the consumer, allowing for ideas and techniques to flow. Barnett and Jackson [28] highlight the role of self-sustained learning within craft communities, where artisans can share their experiences and knowledge digitally to further the development in these settings.

Augmented reality (AR) and virtual reality (VR) have changed the way consumers can engage with craft product, by providing immersive and nontraditional experiences. These technologies shed light on the story behind the crafts, thus giving cultural and historical meanings that bring the consumer closer to the product. Leader Materiality, which tells stories in ways that speak to modern audiences and also celebrate traditional craftsmanship [29] are able to be reimagined through stories and emotions that evoke the imagination in AR and VR.

While new technologies provide exciting new possibilities for the crafts, they also bring with them considerable ethical and cultural issues. One of the main worries is the risk of losing the traditional handmade skills that are an underlying part of our culture. The uptake of new technologies by craft practices and knowledge systems leads to (the potential sidelining of) traditional methods and knowledge systems, which could in turn result in whittling away some of the world's cultural diversity [30]. We need to find a harmony between the 'old and to new' innovation and preserving the past, original technique but balanced by technologies that enhance, not replicate, traditional processes.

The incorporation of AI and 3D printing technology in craft blurs traditional conceptions of what is authentic and what is original. The interplay between hand and machine, where crafting technologies participate in the design and production process, blurs the boundary between handmade and machine-made [31]. This change

also affects how people value handmade items that are created digitally, possibly detracting from understanding the cultural and craft heritage of traditional handmade work. Ethical issues concerning access and equity must be considered when introducing new technologies.

These potentials turn craft production into a more democratic activity in terms of access and opportunities [32] on the one hand, but it also has the ability to reproduce inequalities on the other. These innovations can drive a wedge in the craft community if some artisans cannot take up the innovations due to a lack of technological know-how or equipment. We need policies that not only promote access to the tools of the craft but also enable the support that allows for inclusive and sustainable craft practices to take hold.

3.2 AI and transforming artisans' identity

With the current situation of ever-changing digital technology, which has permeated into several sectors, not least craftsmanship in the contemporary world, artisans—former gatekeepers of cultural patrimony and production themselves—are dealt in a new landscape where digital tools and technologies are influencing how they construct, conjugate and communicate their cultural lineage into existence. This metamorphosis sparks important concerns regarding technology and how it shapes the identity or cultural identification of artisans.

Digitalization gives artisan new ways and space to explore their creativity, which allows them to explore new creative spaces and cater to a large audience. Väänänen [24] further adds that the contemporary craft is indeed a cultural ecology whose different dimensions can be seen in needs, wants, values, attitudes, tastes and function. From the flavor of how digital devices could invigorate the render for craft in our cultural ecology, we focus attention on innovative ways for artisans to communicate cultural narratives to global publics *via* their craft. For example, artisans can use online platforms and social media to present their work to a world audience [27], which in turn generates a global community along with cultural exchange.

Nevertheless, artisanal practices are integrating technologies, albeit with caveats. A major worry may be the possibility of cultural dilution as artisans adopt digital tools, which can be in conflict with traditional approaches and ethos. Härkönen et al. [30] claim that the good tradition of skills for the contemporary context is indispensable for cultural resilience, but there is a potential for technological competencies to overshadow it and hence de-authenticate.

For artisans, literally caught between tradition and technology, the struggle over cultural identity remains a major challenge. In the future, as digital tools become more dominant than traditional methods, artisans will face the challenge of safeguarding their core craft values from diminishing or losing them. Learn through practice learning in craft relates to self-sustenance as Barnett and Jackson [28] elaborate; what can serve as the catalyst for development are catalysts in an ecosystem of learning. It basically tells us we should be careful when it comes to the race for progress and not sacrificing such cultural heritage for this or that.

One of the most pressing issues for local artisans is avoiding the stereotype of churning out the same kinds of local cultural formats as ones now produced digitally, such as printing local textiles with modern methods. To avoid this, sustainable craft processes should include the technology in ways that do not destroy the cultural attraction of the traditional craftsmanship [29]. This demands that artisans find out

which technologies resonate with cultural values and beliefs already existing in their society, retaining their identity while being imbued with innovation.

Artisans find new ways of relating to their audience in the digital age, and are connected in different ways. Modern academic discussions about craft and craftsmanship frequently revolve around their contribution to regional growth [33]. According to many observers, formerly artisans are important figures of heritage preservation and of community development, connecting traditional knowledge to current social needs. On the one hand, artisans can use digital platforms to reach a global audience through edited communication. Undoubtedly, it seems important that Skype Connections are not limited either. Artisans need to dissect these macrophilosophical complexities for their net-digital visibility, from being a part and parcel of cultural identity independently.

Artisans are challenged by the change of identity in the digital era, balancing technology addiction and cultural heritage preservation. This balance is necessary to ensure that innovation is supporting rather than undermining traditional activities. A thing that works well is using new hybrid practices—even blends of digital tools and traditional methods create a good mix that respects culture while encouraging innovation to flow from it. Zhan et al. [32] identify several barriers to the development of craft as a vector for sustainability, such as the necessity for artisans to adapt to technological trends and at the same time preserving their roots in the cultural heritage.

Shared physique heritage in purpose-built environments encourages a shared understanding of history, a sharing of knowledge and of values, and a development of the network of consensus required to deepen cultural identity. For craftsmen, these spaces are where one learns from other craftsmen and traditional practices are maintained while also learning new techniques. For example, Dai and Hwang [34] discuss the significance of sustainable development learning impacts and develop craft practices-based education, arguing that it is possible for artisans to learn among peers about digital tools and sustain traditional techniques. In this interactionist mode, artisans have a collective space where they can try out new technologies and not lose their cultural roots.

Mentorship and apprenticeships are important ways that artisans can adapt to the shift in their self-definition in the digital world. Then, as Kokko and Räisänen [31] emphasize, mentoring is also critical for transmitting cultural knowledge from one generation to another, which is necessary for the survival and evolution of traditional crafts, such as textile production, in specific geographical locations. Engaging in apprenticeship programs using digital tools, the artisans can teach themselves about preserving their traditions while engaging in new methods that will advance their craft.

3.3 Practice, materiality and digitalization in the craft sector

Crafting traditions are part woven heritage and part artisan hand. Materials and techniques are also more than simple means to an end; they are cultural values and history, and the continuity of human culture, the passing from one generation to the next of social traditions and mores. Indigenous materials—clay, wood, textiles, metal, etc.—have played an important role in crafts across various cultures, each being influenced by the resources and environment of the area. Such kind of stuff is more than “just” physical items, they preserve stories, traditions and identities that shape the spirit of its culture [35].

Traditionally, crafts were used to preserve culture and are also considered containers of indigenous knowledge and practices passed from one generation to another. A story of cultural identity and continuity is embodied in objects such as those produced through traditional methods of pottery, handed down through generations: handmade for daily tasks that are considered both ceremonial and ordinary. They are closely linked with community, and are often ceremonial or ritual in nature [36]. This historical perspective is key in appreciating the cultural role of craft and how it has changed.

Just as social systems change, so too do craft processes. There have been all sorts of recent developments too in terms of new materials and technology that have really evolved traditional crafts. The use of synthetic fibers, recycled products and environmentally friendly materials offers new possibilities for creativity and sustainability in traditional crafts. Furthermore, technological developments have greatly facilitated this evolution. Digital technologies (e.g., CAD software, laser cutting) have introduced new possibilities for makers and even contested classic ideas about crafting [37].

The materiality of craft has been transformed by the digital influence, where 3D printing, Computer Numerical Control (CNC) and other technologies are leading to a revolution in how objects are made. With these digital fabrication techniques, craftspeople gained a level of precision and productivity that allowed them to prototype designs beyond the possibilities of traditional trade [38]. This balance between detail and novelty is revolutionizing what it means to make in the digital era [39].

The advent of digital tools has also made materiality a part of craft. Virtual assets, such as digital models and digital instructions, are no exception to present-day crafts. Artisans can see and manipulate their work digitally, theoretically a new dimension in the process of creation [40]. Digital processes offer new as well as traditional means of innovation but also require a reinvestigation of traditional notions of materiality and its cultural values.

In digitalization, the notion of materiality is not limited to the physical but also includes digitized objects and virtual worlds. This expanded materiality upends conventional categorizations of craft and requires a wider interpretation of what might be considered a craft object. With the ongoing development of digital technologies, the line between the physical and the virtual is becoming increasingly diffused, and new opportunities for craft have emerged [21].

The juxtaposition of high-tech methods and old-world skills emphasizes the flexibility of the craft sector—the new and old rub shoulders, and adding digital tools to old crafts has, on the other hand, produced hybrid kinds of work blending the ancient and the modern. It is also a fascinating mode of self-expression and a form of dialog between old and new generations of craft practitioners. They are examples of how traditional hands-on activities can be transformed into digital environments and how new narratives and identities can be constructed in the “field of the making” [41].

The impacts of digitalization on the craft sector are manifold in material and cultural ways. Methods and materials are reaching back into the past, and for crafts, as cultural moorings in a place of rapid transformation. But technological breakthroughs and the advent of new digital tools have established new horizons for craftspeople who redefine what it means to work with matter and skill. Elsewhere...and as makers transition into the digital age, they navigate innovation and heritage, where craft is both preserved and future-proofed in emergent technologies [42].

3.4 Communities of practice and sustainable learning ecologies

The communities of practice (CoP) assure the sustainability of craft by transcending the old and new in connection with the craft. According to Wenger [43], these communities are groups of people with common interests, who interact intensely, they exchange information, increase and build on their knowledge, and make sense of the craft together as a whole. In craft, these communities are vital as they create spaces where artisans interact and interact on knowledge-, skill- and experience-level. This partnership preserves the cultural memory and promotes innovation by blending in new technologies and techniques.

Practice, by Wenger [43], is a social object; therefore, it must be constantly shaped and adapted by the subjects that participate in it. It consists not in a body of standardized knowledge, but in a complex system that encompasses elements of an explicit nature (instruments, procedures and rules), in addition to tacit components (intuition, sedimented sensitiveness and shared world visions). In craft work, communities of practice take the form of informal collections that share not only ways of doing, but further meanings attached to activities. These forms of space are converted into sites par excellence of learning located which is not simply the training of techniques but also the learning of a new professional identity intimately linked to the community of which he forms part.

One of the critical features of craft work communities of practice is their ability to convert learning into an embodied, situated process. As Fabbri [44] recognized, learning is not a solitary or context-free experience but a participative process stemming from participation in social practices. Hence, as an apprenticeship in the craft, this also involves not only learning the craft but also becoming a member of a community where the apprentice is transformed into a crafter. This theory of learning, as represented by Wenger and Lave, relies on the apprenticeship metaphor of a “social trajectory” through the group, where participation depends on one’s ratio of increasing and decreasing involvement until a community of practice is formed. The practitioner learns by doing but also by negotiating and sharing knowledge within the community.

Within the world of craftsmanship, the secrets of the trade can become a source of prestige, and the more I share them, the greater the recognition I will receive from the professional community. The art of brewing is often learned in formal contexts through processes of knowledge exchange that contribute to the creation of a common culture made up of examples, paradigms and best practices. These are informal communities based on practice, not necessarily on profit. In this sense, Wenger [43] defines practice as a social construct, highlighting how it requires individuals to continuously reshape, adjust, and revise their actions and the meaning associated with them.

A practice is not something given; it is not standardized knowledge. In fact, a practice includes both the explicit and the tacit. It includes what is said and what is not said; what is represented and what is assumed. It includes language, tools, documents, images, symbols, well-defined roles, specific criteria, codified procedures, internal regulations and contracts that various practices make explicit for a whole range of purposes. But it also includes all implicit relationships, tacit conventions, subtle allusions, unspoken rules of thumb, recognizable insights, specific perceptions, established sensibilities, implicit understandings, underlying assumptions and shared worldviews. Many of these things will never be made explicit, but they unmistakably signal membership in communities of practice and are crucial to the success of their activities [43].

Communities of practice are crucial to learning and making, and these small, ad hoc links allow sharing of knowledge, techniques and interpretations of skills. They function as repositories of culturally significant knowledge and as dynamic enterprises that prosper within sustainable learning ecologies, facilitating new ways of being and doing by reorganizing knowledge and resources creatively and collaboratively.

Although Communities of Practice (CoPs) in craft work are known not as social fabrication, they do constitute dynamic systems that benefit significantly from sustainable learning ecologies. Sustainable craft, according to Väänänen [24], has been an element in human evolution for centuries, combining ecological concerns with cultural preservation. This will allow different artisan communities to adapt and learn new things over time, enabling sustainable practices. The communities also provide an avenue to innovation by pooling resources, tools and working methodologies so artisans stay faithful while reinventing themselves.

What is more is that the community of practice is not only for the sake of the exchange of knowledge. Second, Illeris and Riis [26], the sensory impressions of working with natural materials are an important basis for Education for Sustainable Development (ESD) in arts and crafts, as they can help to strengthen the bond between crafts persons and the material world.

Community of practice in craft work is a place where collaboration and sharing knowledge lie at the core. Zhan and Walker [27] reveal how craft and design have strayed from natural sustainability concepts toward principles that contain ecology and craft as well as being entwined. As a member within these communities, artisans come together to find new, creative ways of embedding ecological concepts into their craft. The knowledge sharing not only enriches the craft products, it also galvanizes the craft industry as a whole in terms of sustainability.

Moreover, communities of practice help overcome the barriers to sustainable craft development. Barnett and Jackson [28] express how varied knowledge praxis, such as learning cities, acts as a drama for change that can be derived from craft knowledge. Craft communities perpetuate sustainable self-feeding learning, which enables artisans to combat the struggles created by modern and cultural advancement. Such empowerment is an essential step in balancing cultural sustainability with innovation.

4. Theoretical framework: Hybrid artisan learning ecologies

The hybrid learning ecologies in craft practices are based on conventional teaching methods and technological solutions, and aim at providing diverse and evolving learning contexts. This model is built on five core dimensions: Multimodality, distributed learning, learner agency, expanded embodiment and problem-oriented reflection. Together, they introduce new and unique dimensions to changing how we learn craft, providing crafters the means to engage and re-imagine their practice and learning.

4.1 Multimodality: Integration between body, physical materials and digital platforms

Multimodal refers to the fact that in learning, several forms of representation and experience appear simultaneously and are integrated—manual gesture, visual,

auditory and digital [45, 46]. In the world of crafts, this means the simultaneous existence of traditional tools like chisels and looms, and more contemporary ones like digital modeling software (CAD), laser cutting and 3D printing. This “interface” between analog and digital modes opens up new expressive and formative potentials for the crafts.

As Ingold [16] reminds us, “Perception is active, embodied and relational,” and hence it means acknowledging the body and sensorial experience as central to learning. It is this digital approach to crafts that requires activating multiple modes of attention and expression, bridging sensory knowledge and technical mediation. Such an integration is not directed at the substitution of the body with the machine, but at a widening of the artisan’s sensual and expressive field. The digital interface acts as a mediator between a number of ways of knowing, laying mediation on top without breaking completely with the tactile and bodily making.

Craftwork, in the formulation of Marchand [47], is a multimodal enterprise that takes visual, tactile, aural and kinesthetic channels of expression to make meaning. In this respect, hybrid learning ecologies call for pedagogical approaches that appreciate this complexity—they value experiences which blend digital tutorials with tactile exercises and interactive experimentation, so as to prioritize the building of substantial knowledge, which is equally grounded in tradition and in technological innovations [48, 49]. This pedagogical approach, therefore, calls for the development of learning environments that facilitate sensorimotor experimentation as well as technical reasoning and visual thinking.

Rather than dividing theory and practice, or online or offline work, theories now propose that learning is situated, that is, knowledge is produced out of action and is rather intimately connected with the environment and materials. Maker studios, fab labs and hybrid workspaces are emblematic of this kind of space, where disciplined practices, iterative thinking and material invention are all celebrated together. In that senses, “to err” and “to improvise” are not to fail, but to be protagonists in the learning process, which adds to the idea that artisanal knowledge is performed by the body with the use of tools and technology [16, 46].

In that sense, multimodality positions itself not just as a didactic resource, but as a sort of epistemology of doing—a legitimate, complex way of making knowledge. Here, artisanal digital learning takes on a relational and co-design aspect. As Ryberg, Davidsen and Hodgson ([50], p. 1) note, the integration of networked learning tools provides for collaborative, co-created educational experiences, in which learners are provided with spaces for knowledge sharing, ongoing feedback and live collaboration.

This contrasts with other linear and transmissive models of pedagogy by creating a form of learning, which is fluid, adaptive and experience-based. When mediated by technological means, artisanal learning becomes a highly multimodal experience that has opened up access to a large mass of resources—videos, forums, tutorials, simulations—and to communities of practice around the globe. This expansion of the pedagogical field of action crosses geographic boundaries and reinforces the idea of a hybrid ecology of artisanal knowledge, in which knowledge is constructed from the articulation between body, technology, material and networks of social learning.

4.2 Distributed learning—From the classroom to a virtual setting

Distributed learning is an important aspect of hybrid learning ecologies, since it increases the access of artisans to a variety of knowledge, practices and resources beyond their local contexts. This point of view highlights the necessity of enabling

learners to connect to knowledge networks across geographic, cultural and institutional boundaries [51, 52]. Through interviews and observations, we have found that craft workers can join online social communities, participate in virtual workshops and share resources with experts and peers around the world to facilitate situated, connected learning. Distance learning, then, does not only extend the access to knowledge but also encourages the collective creation of knowledge and the consolidation of communities of practice [53].

Green, Carvalho and Sheridan [54] stress the importance of constructing authentic signs within hybrid spaces that coax learners along nonlinear and deeply contingent learning paths. These are interpretive cues that help young people to home in on the various levels of experiences, media and interaction that together make up the modern artisan learning ecology. Distributed learning, in this case, enables a sharing of tacit and explicit knowledge while also contributing to the technical, esthetic and reflective dimensions of craft practice. By incorporating digital formats into their craft and production work, the respective craftspeople are able to extend their creative and formative horizons, cultivating competences which are as traditional as they are innovative in terms of technology [46, 50].

In this context, recently enhanced by digital networks, the contemporary artisanal learning requires a pedagogical redesign that offers bridges between local and global knowledge networks. This means not only obtaining content, yet being part of a community of practice, in which processes, mistakes, solutions and innovations are shared [49, 53]. On sites, for example, Instructables, Thingiverse, YouTube and GitHub, makers not only consume tutorials or project files—they add, remix, comment and validate the circulating knowledge in a co-creative process that characterizes the participatory digital culture [55, 56]. This movement casts learners as co-authors and active agents in the digital culture of making.

As Marchand [57] explains, learning through apprenticeship extends across generations and spaces, and occurs both directly as well as through digital mediations. In regard to education, pedagogy would value these interactions over generations and places, seeking an educational process that balances roots in local practices with opening to a transnational network of support and collaboration [51, 52]. By intersecting the physical and informational space of the workshop with flows from the digital, craftsmanship is reinforced as an embodied and networked practice.

4.3 Agency and autonomy in hybrid artisan learning

Learner agency is a crucial dimension of hybrid learning ecologies, referring to people's ability to make meaningful decisions about what, how, when and with whom to learn [58–60]. In artisanal practices, this means to empower the participants to make their learning experience their own, to follow their interests, working at their own pace, for their own reasons, and to take ownership of their own individual technical, creative and cultural path development. Digital affordances (tutorial repositories, design software, and collaborative spaces such as YouTube, Instructables, GitHub, etc.) provide concrete ways to enforce such agency on the part of respondents through content curation, self-directed action and perpetuity of self-evaluation [49, 56]. Forshaw [61] argues that from the history of guild models to the workshop of today, autonomy has always been a key element of artisanal learning, albeit established in a master-apprentice relationship.

Furthermore, as Kumpulainen and Sefton-Green [62] suggested, agency is not the product of an isolated individual but is rather an effect of the socio-technical and

cultural networks in which the learner is involved. And second, by bypassing a reliance expose to masters in centralized schools, artisans become enmeshed in interacting ecologies of meaning-making, validation and knowledge flow. This relational sense of agency contributes to the sense that the author is responsible for what he or she has written and learned and is thus more actively engaged in what is being learned and adds to that heuristically led learning to make it more authentic and intrinsically motivated learning [45, 46, 48, 55]. Agency thus becomes a central plank of creating more inclusive, responsive and sustainable learning ecologies, supporting artisans to learn with, through and about the networks they are a part of.

In this sense, agency for learners in mediated hybrid environments also transcends autonomy, authorship and support, all combined with responsive and iterative ecologies: Analog and digital, involving themselves. Papert [63] discusses constructionism and equates technology-mediated learning with something more than learning how to use tools and the development of “a programmer’s identity”—a way of engaging with and changing the world as a creative and transformative force. In the craft of the digital, this philosophy surfaces in software for simulation or modeling, in tools for fabrication like CAD, CNC, 3D printing and laser cutting; they provide cognitive and expressive extensions of handcraft. Decisions taken about the algorithms used, the parameters chosen, and the material adopted; however, become ways of telling about oneself, of questioning personal values, cultural repertoires and life stories [55, 64, 65].

But creative freedom does not mean a lack of support. In order to have a productive freedom of experimentation, there is a need for adaptive pedagogical support sensitive to learning rhythms, pathways and styles. Here, Vygotsky’s [66] zone of proximal development is used to inform digital scaffolding, or temporary support mechanisms like contextualized tutorials, just-in-time feedback, virtual assistants and the mediation of human tutors in synchronous environments. These forms of mediation allow learners to intervene when they encounter an obstacle without threatening autonomy and thus provide space for reflective agency in a good balance between challenge and support [67, 68]. When authors’ identity and technical knowledge coincide within a digital artisanal practice, such practice becomes a situated formative practice that is focused on experimentation, dialog and meaning-making.

4.4 Gestures and algorithms: Embodied pedagogy in hand crafts

Extended material embodiment is a crucial aspect in hybrid learning ecologies, and especially so in artisanal instruction, emphasizing the interwoven physical and digital in educational processes. This dimension emphasizes the importance of incorporating the material and virtual on the basis of being able to develop an integral learning that activates perception, technique and sensibility. In today’s artisan practices, the integration is made possible through technologies from augmented reality, 3D simulation, digital fabrication and sense-aware devices that extend traditional methods. Goodyear [69] contends that hybrid learning spaces can only be designed through innovative approaches that can retain a sense of the meaningful and integrate into environments where the artisanal intertwines with computational mediation. By introducing these to the day-to-day workshop, makers gain access to new technical repertoires but also modes of perception and action that help configure their author model across media, languages and materials [70, 71].

This kind of technical incorporation does not contradict corporeality so much as it elaborates it. Merleau-Ponty’s [72] phenomenology of the body offers a philosophy

of the body that helps explain how the body continues to be at the heart of experience (including digital media mediated experience). Artisanship is still shaped by gesture, attentive feeling for materials and improvisation. Marchand [57] echoes this idea by suggesting the body as an epistemic tool: That is, as a way to think and learn with action. It operates the fold without discarding the manual gesture, which is rearranged, allowing it to be projected with modeling software, algorithmic parameters and parametric fabrication tools. Examples such as distant production, generative design or mixed reality use show how craft still takes a bodily form, even when mediated through computational artifacts [16, 73].

By way of extending this line of inquiry, posthumanist and materialist methodologies offer a habitus to apprehend the connections between body, technique and mediation in new ways. Hayles [74], referring to embodiment in digital environments, claims that technology neither cancels the body nor absorbs it, but organizes it. Barad [75] coins the term “intra-action,” by which matter and agency result from the interaction between humans and artifacts, and the dichotomies between subject and object fade away. For the purposes of this investigation, in artisanal learning situations, it means to see agency as distributed in and among bodies, tools, materials and algorithms [76]. This view expands on the concept of extended embodiment to include embodied, sensorimotor learning that is, in addition, technologically mediated and occurs in complex networks of action. Within this hybrid ecology, artisanal knowledge is created through relationships of attention, sensitivity, code and matter—what we might understand as a pedagogy of an expanded gesturality that is technosensitive.

4.5 Reflecting and problematizing hybrid artisanal learning

Reflection on the problem is an essential aspect of craft-centered hybrid learning ecologies, as this emphasizes the integral role of critical thinking, context-dependent decision-making skills and notions of emergent design throughout the creative product process. Inspired by pragmatist legacies [77] and by Schön's [78] notion of “reflection-in-action,” this dimension challenges an educational perspective based on the recurrence of practice, expecting what the participants experiment to be in a certain way repeated as often as possible and with the greatest fidelity possible, or an educational view where one arrives at learning only after having listened to (and understood) a course or a teacher. In the field of craftsmanship, this corresponds to the capability of a learner to recognize and respond to material, technical or esthetic challenges with innovative solutions, building his/her knowledge reflexively and experientially. Digital platforms—software for prototyping and simulating, collaborative forums and feedback systems—further seem to strengthen this process of continuous monitoring and of charting and comparing of outputs against various parameters [49, 56].

Flanagan and Xue [79] examine hybrid artistic practices that engage with material with its physical and digital makeup, and show how these practices require an ongoing reflection of what a tool allows or prevents an agent to make. Through the coupling of these computational codes with manual gesture, these creative practices provide makers with open-ended problems, which question assumptions and offer the possibility to adapt the real-time process. Drawing from ethnographic work with craftspeople, Marchand [57] highlights that mistakes do not mean failure; it is a structural component for learning, which creates a turning point enabling improvisation and skill generation. As the author says, the process of making is not additive; it is not

just accumulating bits of knowledge about how things work, but it is a crescendo of attempts and mistakes, surprises and creative solutions that reach an intense period of learning. Thus, problem-focused reflection promotes not only technical progress but also fosters an investigative, independent and adaptive attitude to craft.

This educational model differs from the tradition of mechanical reproduction and is based on the closure of the algorithmic action, which streamlines learning. In craft, and hence in digitally mediated forms of craft practice, error is an epistemic instrument: Seeing what goes wrong in the process of doing helps in turn to develop gestures, to reconfigure processes and to gain an understanding of the materials, the tools but also the limits and possibilities of one's own body. Learning is thus a space of sensitive creative exploration in which failure is revalorized as a productive part of the learning process [46, 55]. Pedagogically, this requires project-based models, labs and maker spaces, experimental approaches and practices that invite creative risk, shared reflection, and the valuing of emergent learning. In such a situation, hybrid hand-making becomes a reflexive and recursive educational process in which each problem is used as a basis for learning.

4.6 Empirical insights: Case studies of hybrid craft learning

Hybrid learning ecologies in artisanal practice in artisanal practice, hybrid learning ecologies have become a revolutionary approach, combining the best of craftsmanship traditions with digital technology. In this chapter, we consider examples of a number of case studies that vividly illustrate the implementation of hybrid learning ecologies within craft practices. Each of the case studies accentuates a specific dimension of hybrid learning ecologies, such as multimodality, distributed learning, learner agency, expanded embodiment and problem-oriented reflection.

The first case study examines examples where multimodal digital environments have extended and enriched learning craft. As a concept, multimodality is the practice of using more than one mode of communication and learning, to facilitate learning in a rich learning environment (including all the elements from visual, auditory and kinaesthetic learning). Within the realm of the craft arts, this means the use of digital tools such as video, interactive software, and online communities to supplement traditional hands-on instruction.

This is exemplified in a study by Ryberg et al. [50], which is particularly relevant to the significance of networked learning for enabling multimodal experiences of primary school open digital apprenticeship (ODA) students doing craft. By using tools like online video chat and digital design software, craftsmen have an abundance of resources to enhance their education, which goes much further than the basics of what they learn in a hands-on class. This multimodal strategy enhances the breadth of learning and meets various learning styles, leading to a more inclusive learning environment.

The second case looks at distributed learning, a key component of hybrid learning ecologies that allows artisans to tap into varied resources and expertise beyond their immediate local settings. Distributed learning draws from community and shared expertise to bring students into contact with peers, mentors and professionals locally and from around the world to enhance the ways they learn.

Green et al. [54] have pointed out the necessity of creating authentic indicators in hybrid learning contexts and the significance of distributed learning in developing collaborative networks. In practice, this is seen in apprenticeships or guilds of craftsmen sharing knowledge over the internet across different locations, problem-solving

together and learning together from colleagues. It democratizes access to knowledge, defies geographic distance and creates a feeling of fellowship across artisans—an important requirement in achieving continuous learning and promotion.

A further key dimension of hybrid learning ecologies is learner agency, where individuals are able to take sustained ownership and responsibility for their learning pathways and decisions. This case story addresses the way in which the craftspeople have engaged with technologies in their lives, using them to customize learning experiences and build their own learning pathways based on their personal conditions and professional interests. In the article by Song [36], ‘Fifteen professionals and three hobbyists enrolled in a workshop focused on 3D printing, laser cutting and 3D modeling. External (e.g., peer pressure, market influencing factors) as well as internal (e.g., customization and visualization of ideas) motivations influenced the participants in defining their learning paths, choosing software or materials on the basis of their own objectives. The research illustrates that learner agency is enhanced when artisans have a say on modules, their pacing and the challenges they embrace according to their interests, creating a relationship with technology as an extension of their creative identity.

Forshaw [61] examines the craft-based traditional apprenticeship learning ecologies and how technologies are influencing these modes of learning. As digital offerings such as online courses, virtual reality simulations and personalized learning platforms are blended in, the artisans of the future can take ownership of their education, choosing what resources and modules they need to meet specific learning objectives. This freedom boosts motivation and results in greater investment in the craft, as students are enabled to learn more about the aspects of crochet that interest them, and take the initiative to experiment by trying out new techniques.

Hybridity in craft education can be approached from the framings of expanded embodiment. This paper explores how digital tools have enabled a transformation of physical craft practices by providing craft practitioners with new opportunities to work with their hands.

Goodyear [69] considers the complications of designing hybrid learning spaces and the possibilities of extended embodiment for enhancing craft practices. One popular example is the ability to “try before you buy” through AR and VR applications so creators can visualize and modify digital representations of their work before taking physical form. This fusion of the digital and physical has the potential to increase precision and creativity and to foster live experimentation and iteration, leading to more nuanced and innovative craft practices.

Finally, a case study examines the influence of problem-based reflection on enhancement and innovation in craft practice. This aspect of hybrid learning ecologies highlights the need for andropodic thinking and responses that enable craftsmen to think about their practice, identify issues and determine aids in the process.

Flanagan and Xue [79] explore creative practices that combine digital and material components, illustrating how a form of problem-based reflection can induce creative breakthroughs. Artisans active in hybrid learning ecologies are advised to take an analytical distance toward their practices; using digital instruments to document, analyze and optimize provides this distanced look. This reflective mindset creates an environment for evolutionary improvements and new creative directions; this allows craftsmen to respond to changing trends and start using new techniques.

Together, the case studies demonstrate the transformative power of hybrid learning ecologies in craftspeople. Through multimodality, distributed learning, learner agency, expanded embodiment and problem-oriented reflection, artisans are

further enabled to respond to their craft learning, which could lead to deeper learning experiences and new practices. With the advent of the contemporary craft in a dynamic phase, hybrid learning ecologies become needed for craft practitioners to survive in the digital era.

5. Conclusions

Craft work is undergoing a radical transformation with the increasing presence of digital tools, for example, 3D printing, artificial intelligence and virtual platforms for collaboration. Such innovations make it possible for the production, distribution and expression of culture, with access to a global market and intercultural exchange. And yet, a number of key challenges lie ahead; these include a loss of traditional skills, the ethical sourcing of materials and a reimagining of craft's authenticity. Building on the work of thinkers such as Ingold, Sennett, Marchand, Lave and Wenger and Billett, and informed by the case studies it interprets, it is clear that learning in the digitalized crafts environment occurs within multimodal ecologies—spanning physical and virtual spaces—where learners deliberately hybridize traditional and digital methods. This mode of making is entwined in a form of embodiment which sees attention, gesture and bodily engagement repurposed through novel interfaces. Mistakes, play, error, test and serendipity are not to be shunned; they are not tiresome time-wastage to be side-stepped, but rates of pulse force (epistemological engines) through which knowledge is pushed.

This chapter examined these dynamics through the frame of hybrid learning ecologies as demonstrated by educational settings that encompass traditional and innovation and sustained and invigorated craft making in the digital age. Hybrid learning ecologies are not only fusions of analog and digital tools, but complex systems that encompass multimodal participation, learner autonomy, distributed collaboration and reflective inquiry.

One of the key discoveries is that these ecologies afford creative autonomy, allowing craftspeople to direct their own learning journey. This is particularly important in a field that continues to function on master-apprentice models. When craftsmen couple traditional crafting with digital resources—like 3D modeling, tutorials and virtual workshops—they can create while staying linked to tradition.

Just as important is the social component of hybrid learning. Knowledge sharing, feedback among global users. Community-oriented platforms that facilitate the communication and knowledge sharing between communities around the world are a win-win where both the engineering and the sense of community are boosted. Communities of practice are essential for this process, maintaining embodied knowledge and fostering a common cultural identity.

The impact is far beyond the individual learner. In education systems, in vocational programs, in cultural policy, there is an imperative toward inclusive, multimodal and sustainable pedagogy. Hybrid models that marry in-person workshops with digital resources, emphasize learning from peer artisans and enable creative risk-taking are far more likely to equip artisans to steer a fast-changing world rather than whirl through it. In this sense, the future of craft is not an either/or between tradition and technology. However, it relies on the development of sustainable learning ecosystems where cultural heritage and innovation have continuous interaction. These should be ecologies that support pedagogy that is ethically rooted, culturally sensitive, socially responsible and experimental, fostering craft culture as a living, situated and reflective practice.

At a time of accelerated technological progress and industrial standardization, adopting a hybrid pedagogy of craft is not only necessary for the survival of the sector but also for the safeguarding of cultural heritage, the encouragement of creative potential and the reaffirmation of embodied intelligence as the basis for manual making. Craft, far from anachronism, is revealed as a living and evolving activity that has left as its legacy the possibility of creating meaningful futures.

Within this hybrid ecology, a digital–manual-making reconfiguration of pedagogy emerges that values experiential sensibilities, tacit awareness, the re contextualization of traditional skills through contemporary tools and materials, knowledge sharing within digitized and collaborative networks and empowering participants with their own sense of agency in developing their own and personally meaningful path through learning. In the end, the future of craft will depend on a careful and conscious balance that holds technology at the same time it holds dear the ethical, the cultural and the ecological values which are its essence. Hybrid learning ecologies offer both a desirable and indispensable path: They respect the past, engage the present and (pro) generate a new generation of artisans able to interact with an ever more intricate and interdependent world.

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Conflict of interest

The authors declare no conflict of interest.

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Edited by Larisa Ivascu and Florin Dragan

The volume presents a comprehensive overview of how technology, particularly generative artificial intelligence, is profoundly transforming the labor market and the organization of professional activities. The challenges of future jobs include automation and role transformation, labor market polarization, adaptability and continuous learning, ethics and trust in technology, reconfiguration of work processes, generative artificial intelligence (AI), and job sustainability. This volume highlights new perspectives and research on the future of work, workforce, and workplace. These titles cover a diverse range of topics, including STEM education, workplace innovation, and the role of artificial intelligence in productivity, occupational safety, and organizational sustainability. Many of them focus on how AI and digital transformation are altering the professional environment, while others examine the human and ethical implications of these changes. Artificial intelligence, technological advancements, social intelligence, new risks, and other aspects of sustainability and system engineering are approaches that require research and can contribute to the development of sustainable workplaces and increased organizational competitiveness. There are also works focused on education and sustainable practices, highlighting the importance of adapting and collaborating between tradition, innovation, and social responsibility. Overall, the volume reflects the primary research directions on transforming the workplace in the era of artificial intelligence and global sustainability. The future of work will not be “without people,” but with people augmented by AI.

Sandro Serpa, Social Sciences Series Editor

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